Wind Power Deployment Strategies

NASA Technology Evaluation for Environmental Risk Mitigation Conference

Robi Robichaud, Senior Engineer, Wind Powering American Program
National Wind Technology Center, NREL

Large Wind Deployment Strategies Outline

- Energy – where we are
- Wind energy – environmental benefits & issues
- Wind energy – economic drivers
- Wind resource assessment – example of path forward
- Barriers to 20% wind by 2030
- Wind turbine trends & costs

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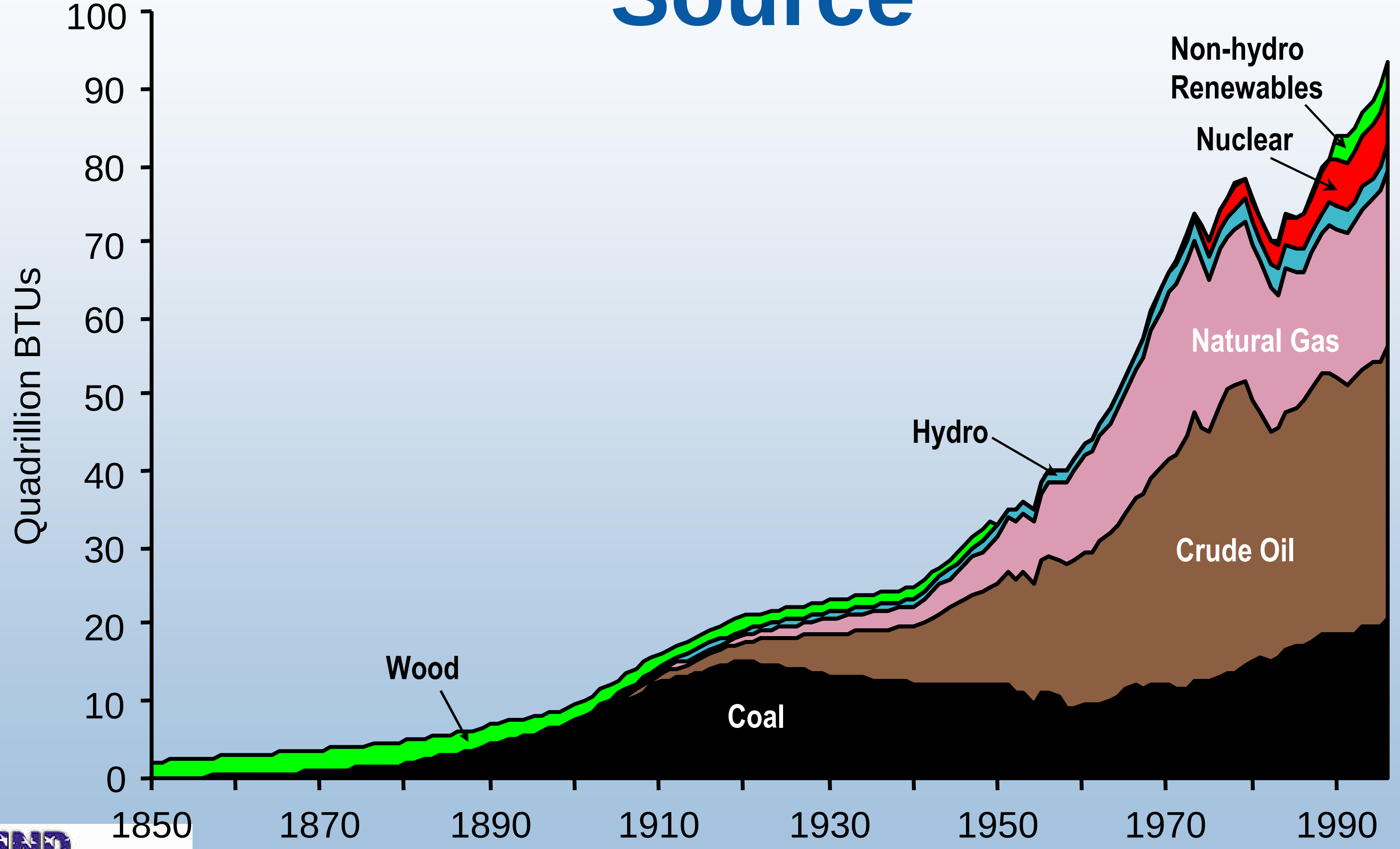
U.S. Energy by Source



Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables.

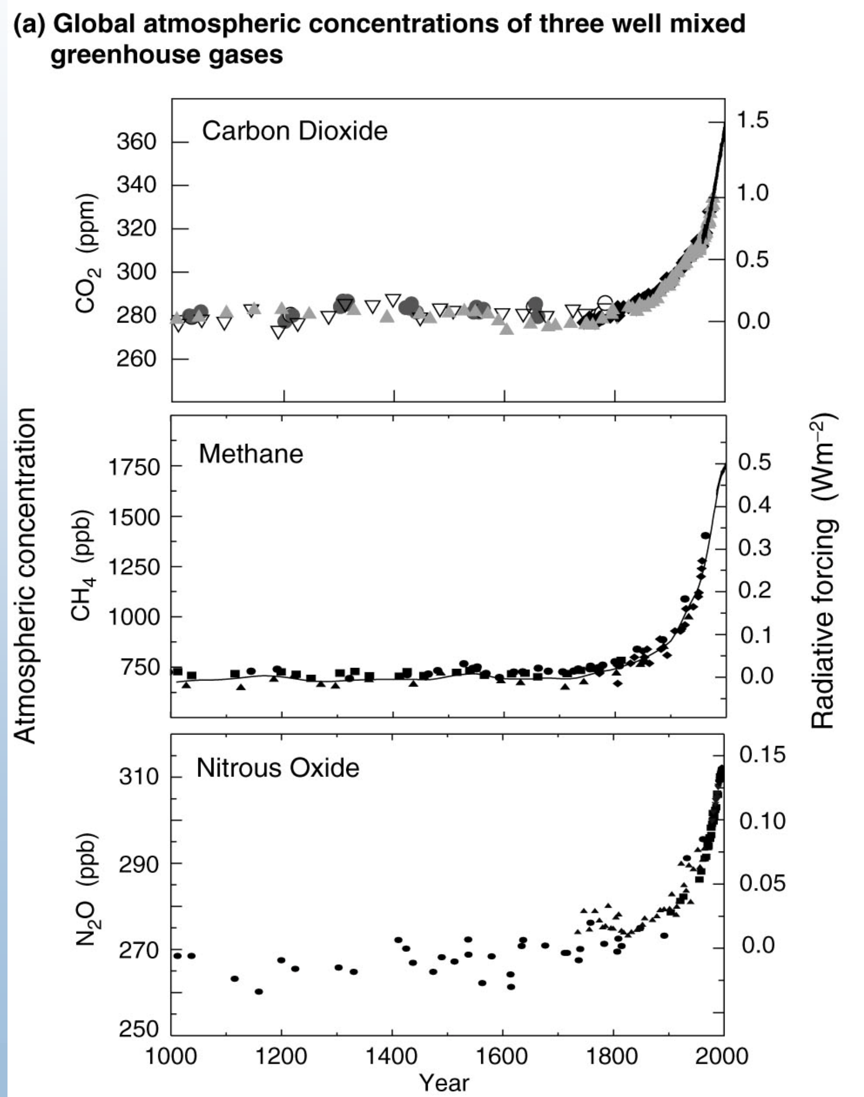
Humanity's Top Ten Problems for next 50 years

1. **ENERGY**
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

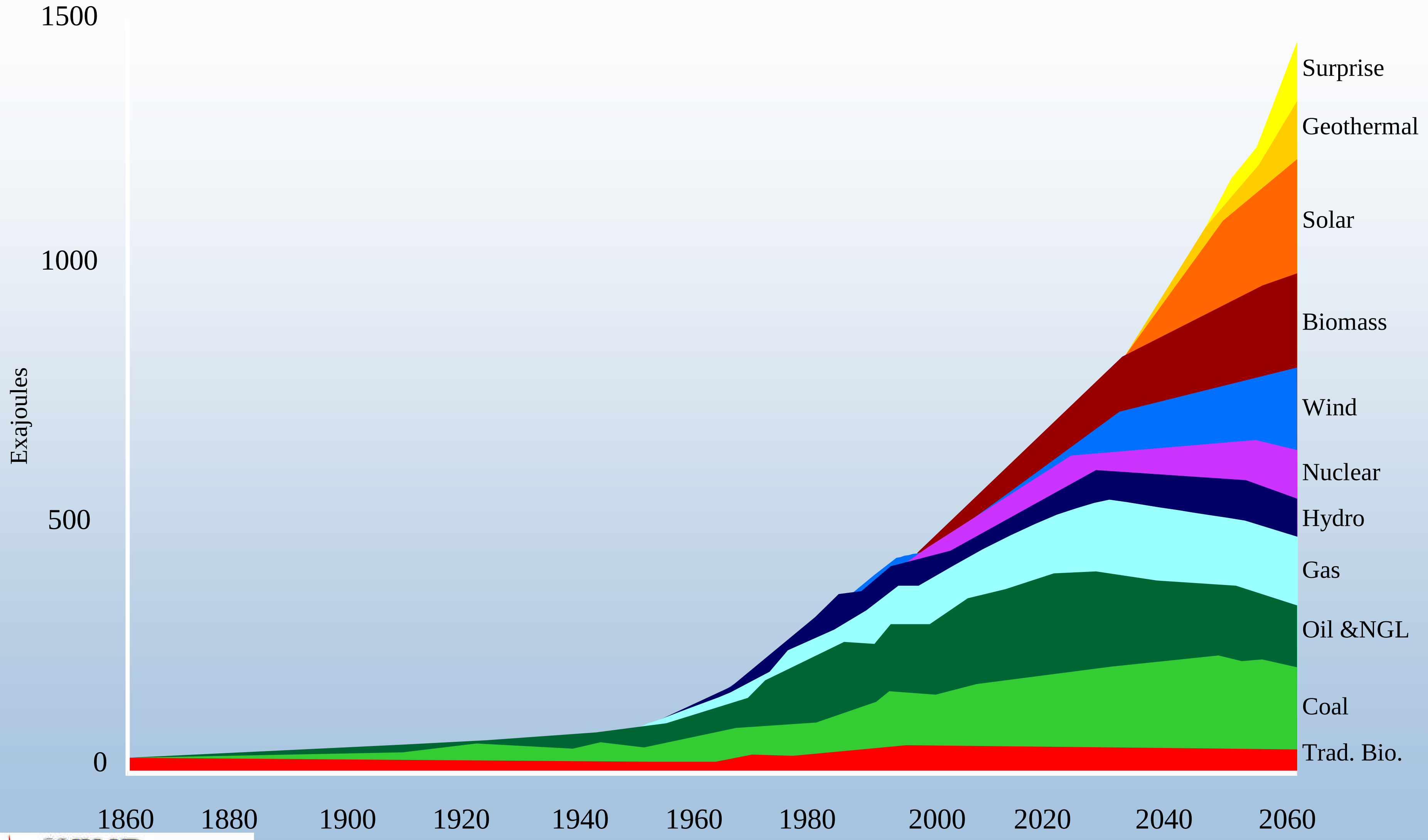
2003	**6.3**	**Billion People**
2050	**9-10**	**Billion People**

Source: Nobel laureate, Richard Smalley

Abundance of fossil fuels is not a blessing, *it is a problem.*



The Future of Energy



Source: *Shell, The Evolution of the World's Energy Systems*, 1995

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Wind – Environmental Benefits

Emissions reductions vs coal electricity

20,000MW – offsets

- ~24 million tons of coal electricity
- equivalent to 80 million barrels of oil

1.5MW wind turbine – offsets

- 1,800tons of CO_2
- 14 tons of SO_2
- 6 tons of NO_x

Source:
http://www.nrel.gov/data/pix/Jpegs/00560.jpg

Wind – Environmental Benefits

Water use

1.5MW wind turbine – no water

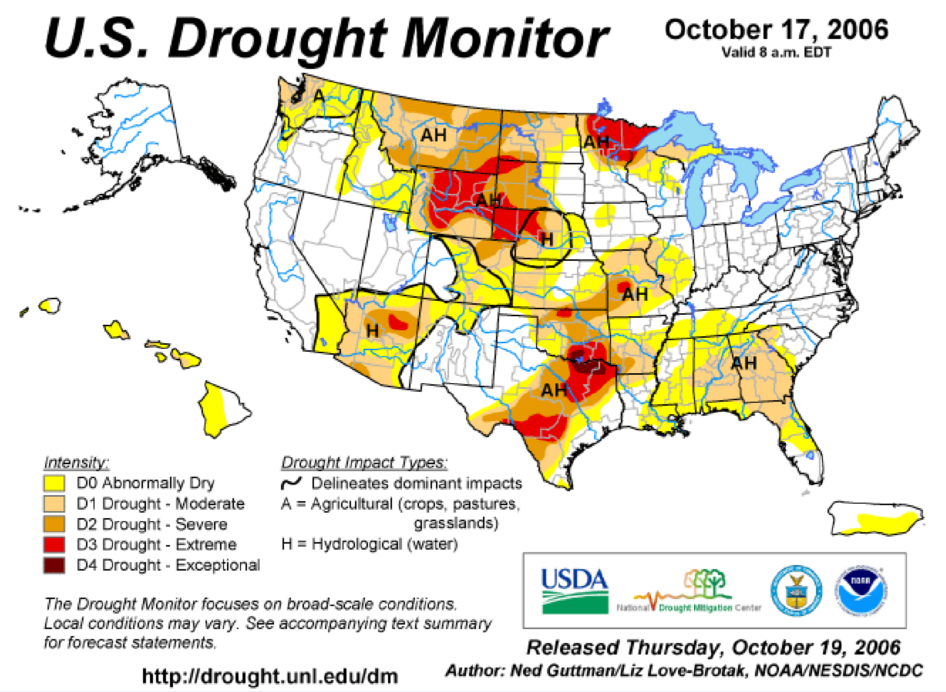
vs.

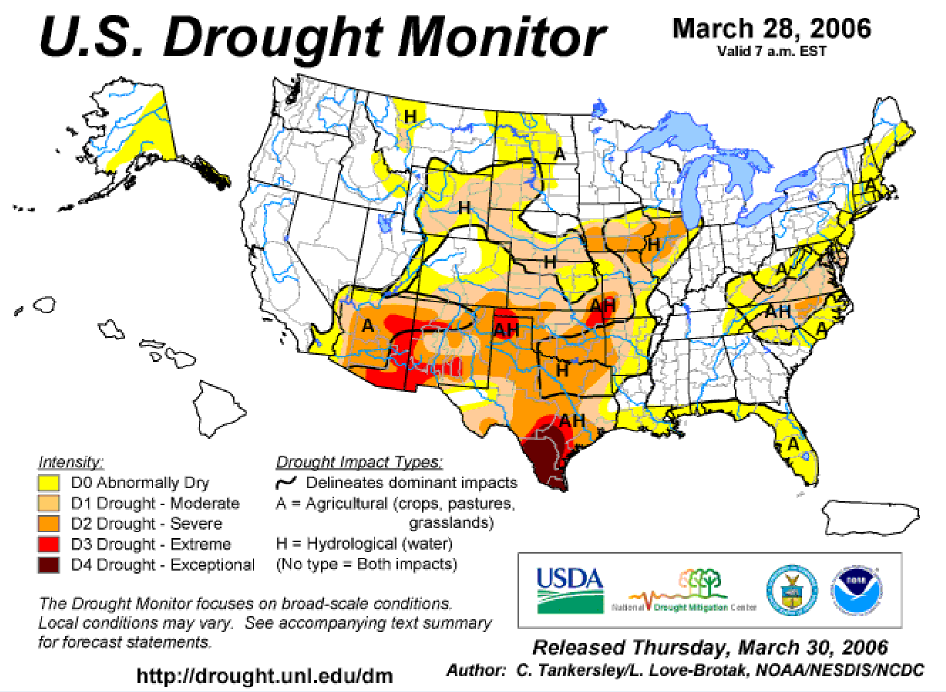
Fossil fuel or nuclear

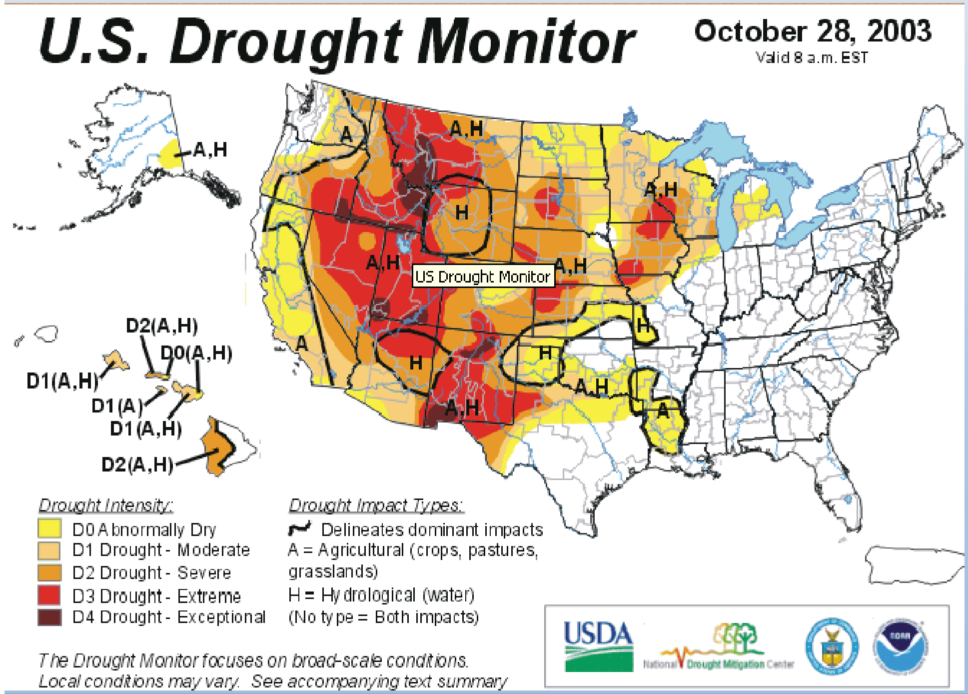
- withdraw 90 million gal
- ~ 1 million gal lost to evaporation

Total Water Withdrawals, 2000

Source: **USGS Circular 1268, 15 figures, 14 tables** (released March 2004 and revised April and May 2004).Available at: http://water.usgs.gov/pubs/circ/2004/circ1268/index.html


U.S. Drought Monitor
October 17, 2006
Valid 8 a.m. EDT
Intensity:
D0 Abnormally Dry
D1 Drought - Moderate
D2 Drought - Severe
D3 Drought - Extreme
D4 Drought - Exceptional
Drought Impact Types:
Delineates dominant impacts
A = Agricultural (crops, pastures, grasslands)
H = Hydrological (water)
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
USDA
National Drought Mitigation Center
Released Thursday, October 19, 2006
Author: Ned Guttman/Liz Love-Brotak, NOAA/NESDIS/NCDC
http://drought.unl.edu/dm


U.S. Drought Monitor
March 28, 2006
Valid 7 a.m. EST
Intensity:
D0 Abnormally Dry
D1 Drought - Moderate
D2 Drought - Severe
D3 Drought - Extreme
D4 Drought - Exceptional
Drought Impact Types:
Delineates dominant impacts
A = Agricultural (crops, pastures, grasslands)
H = Hydrological (water)
(No type = Both impacts)
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
USDA
National Drought Mitigation Center
Released Thursday, March 30, 2006
Author: C. Tankersley/L. Love-Brotak, NOAA/NESDIS/NCDC
http://drought.unl.edu/dm


U.S. Drought Monitor
October 28, 2003
Valid 8 a.m. EST
US Drought Monitor
D2(A,H)
D0(A,H)
D1(A,H)
D1(A)
D1(A,H)
D2(A,H)
Drought Intensity:
D0 Abnormally Dry
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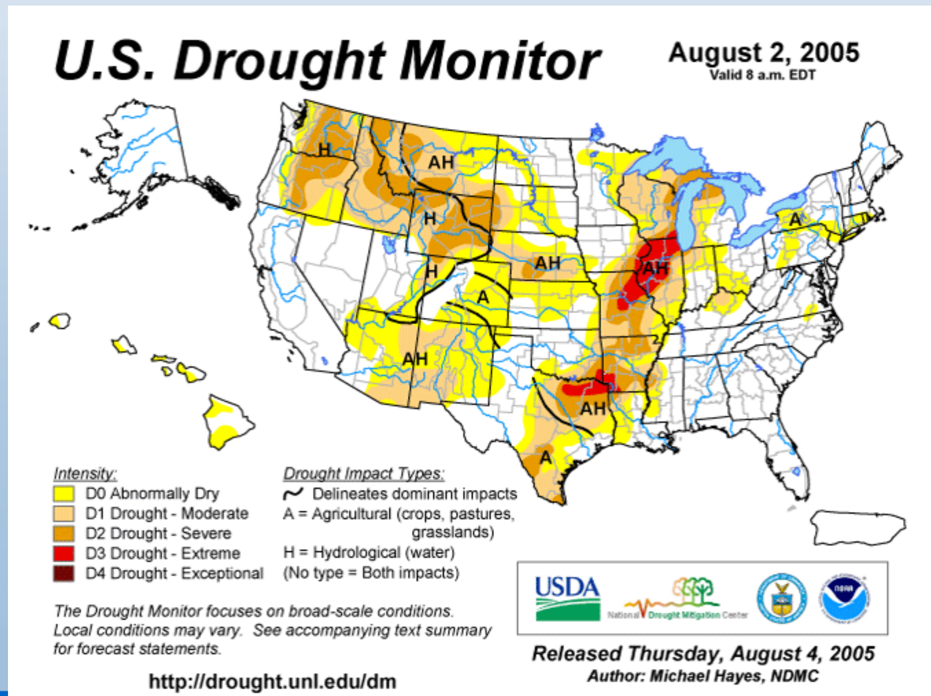
USDA
National Drought Mitigation Center


U.S. Drought Monitor
August 2, 2005
Valid 8 a.m. EDT
Intensity:
D0 Abnormally Dry
D1 Drought - Moderate
D2 Drought - Severe
D3 Drought - Extreme
D4 Drought - Exceptional
Drought Impact Types:
Delineates dominant impacts
A = Agricultural (crops, pastures, grasslands)
H = Hydrological (water)
(No type = Both impacts)
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
USDA
National Drought Mitigation Center
Released Thursday, August 4, 2005
Author: Michael Hayes, NDMC
http://drought.unl.edu/dm

Wind – Environmental Benefits

Embodied energy

Wind energy production time to offset manufacture and construction energy – **4-5 months**

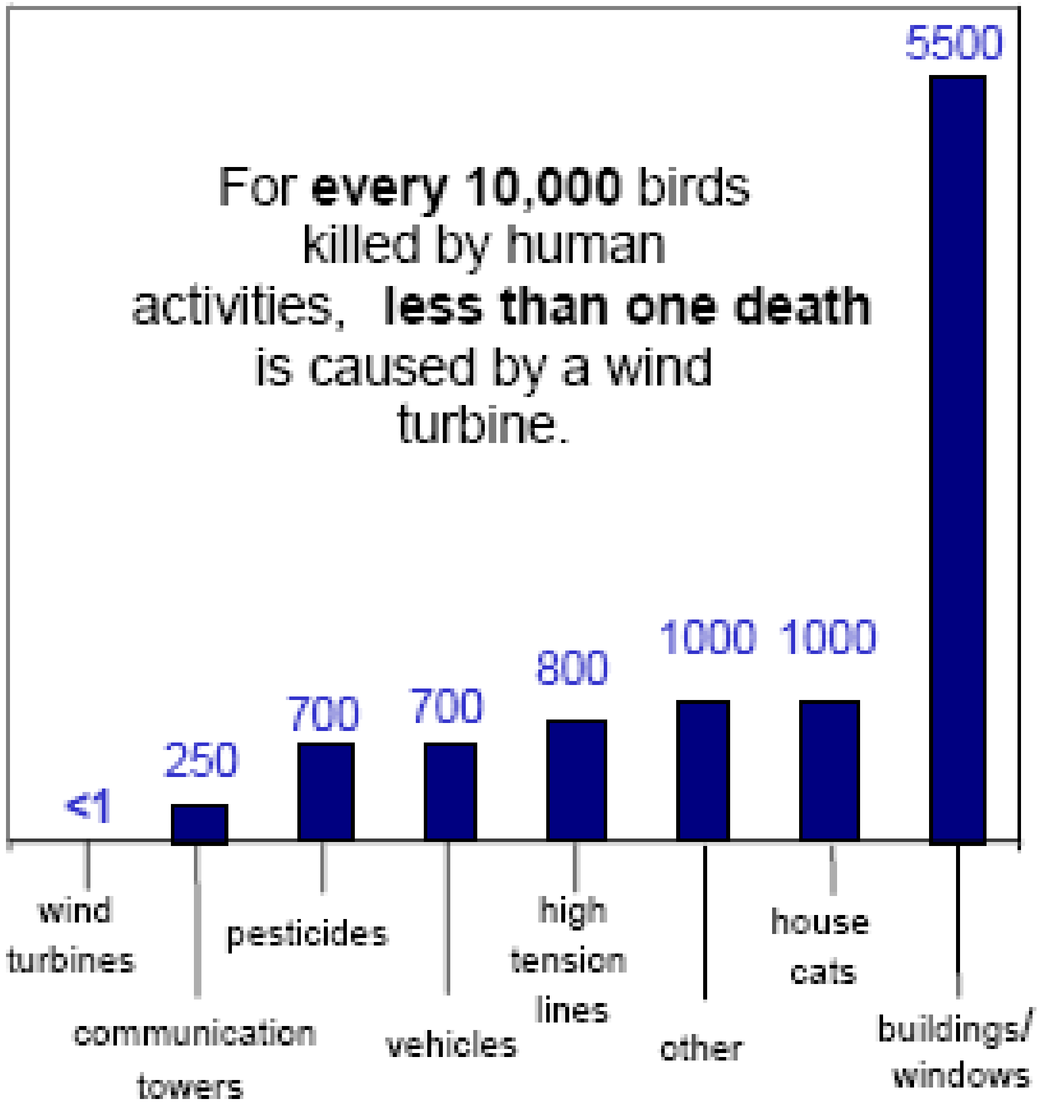
Photovoltaics – 2-3 years

Nuclear and coal – infinite (more embodied energy than they produce)

Source: http://www.awea.org/wew/851-1.html

Wind – Environmental Issues

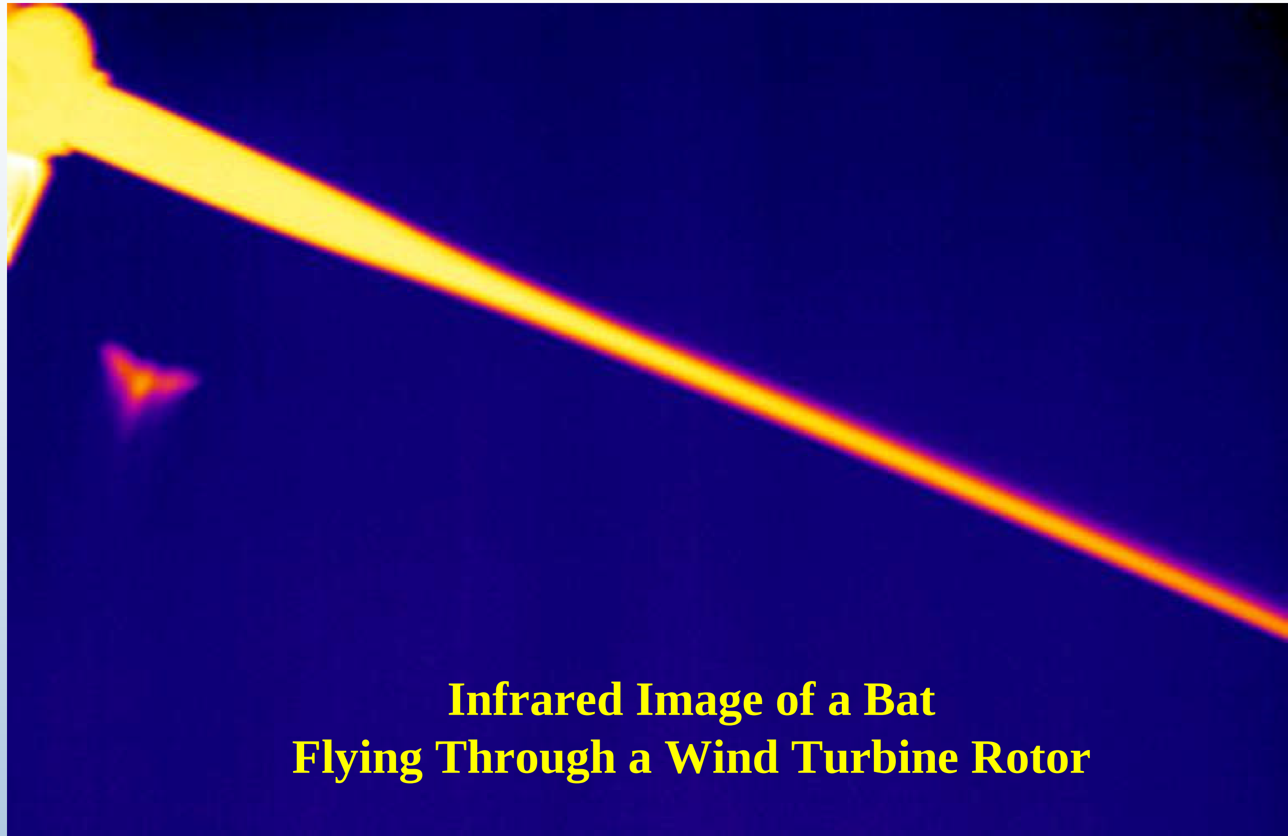
Avian Impacts of Wind Development



Data source: Erickson et al., 2002, Summary of Anthropogenic Causes of Bird Mortality.

Multi-Stakeholder Wildlife Research

- **National Wind Coordinating Committee**
- **Bat & Wind Energy Cooperative**
- **Grassland Shrub Steppe Species Collaborative**



Jason Horn, Boston University

Drivers for Wind Power

- Declining Wind Costs
- Fuel Price Uncertainty
- Federal and State Policies
- Economic Development
- Public Support
- Green Power
- Energy Security
- Carbon Risk
- Water Usage

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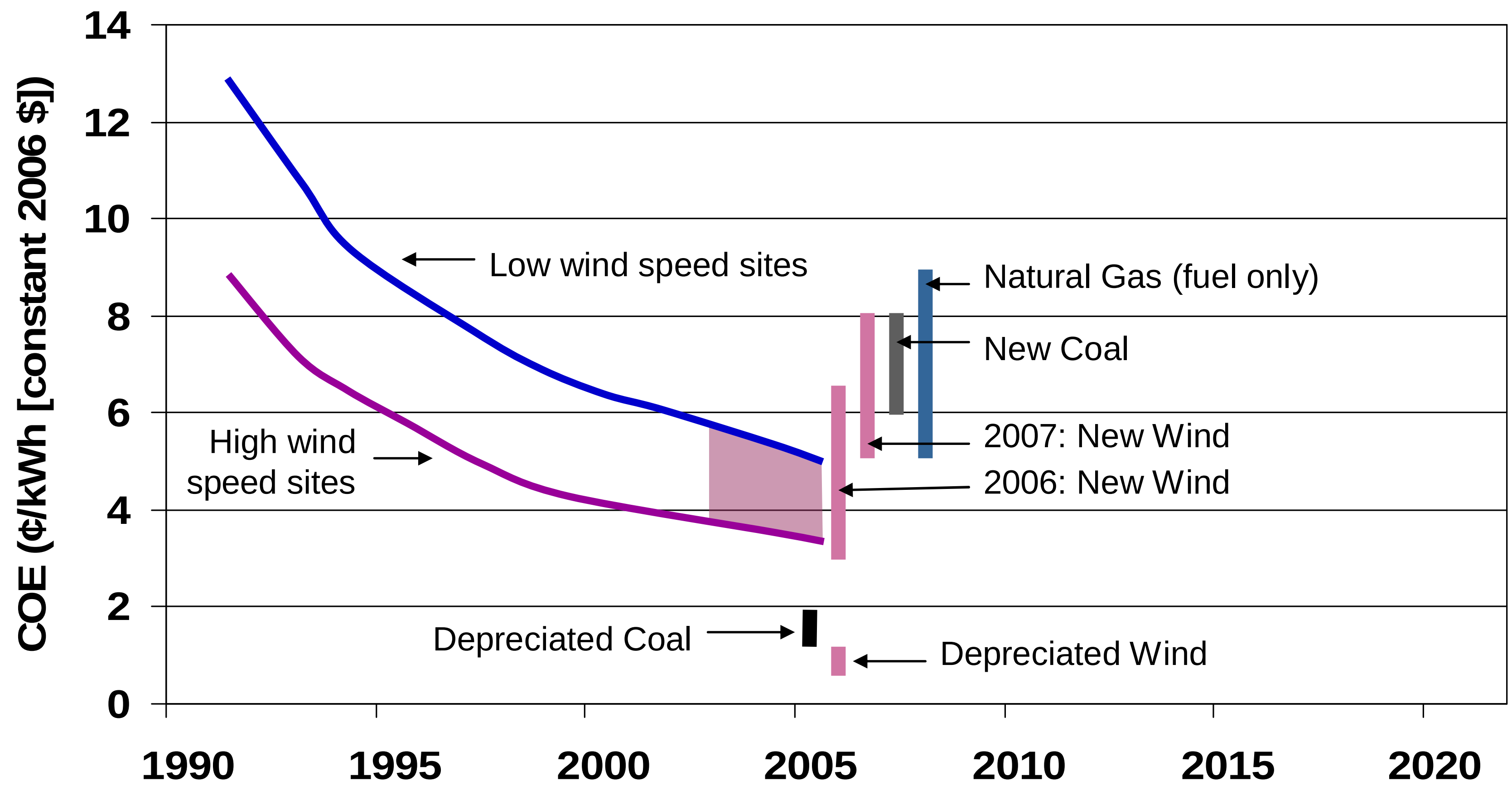
Wind Cost of Energy



Nebraska – Economic Impacts

from 1000 MW of new wind development

Wind energy's economic "ripple effect"

Direct Impacts

Payments to Landowners:
- $2.7 Million/yr

Local Property Tax Revenue:
- $3.9 Million/yr

Construction Phase:
- 1,650 new jobs
- $189 M to local economies

Operational Phase:
- 250 new long-term jobs
- $21 M/yr to local economies

Indirect & Induced Impacts

Construction Phase:
- 1,650 new jobs
- $149 M to local economies

Operational Phase:
- 200 local jobs
- $18 M/yr to local economies

Totals
(construction + 20yrs)

Total economic benefit = $1.1 billion

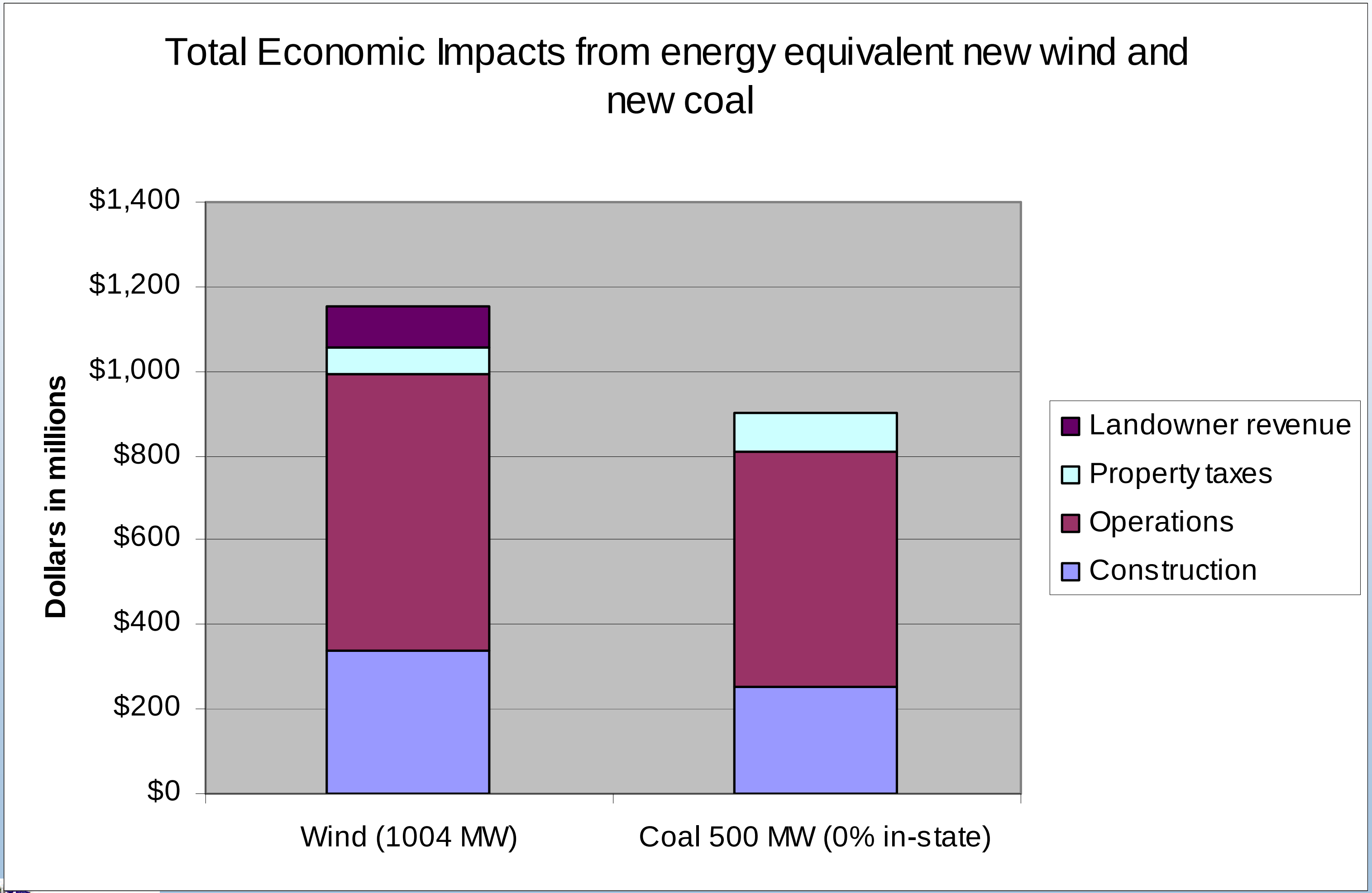
New local jobs during construction = 3,300

New local long-term jobs = 450

All jobs rounded to the nearest 50 jobs; All values greater than $10 million are rounded to the nearest million

Construction Phase = 1-2 years
Operational Phase = 20+ years

Energy-equivalent
New wind vs. New coal in Kansas



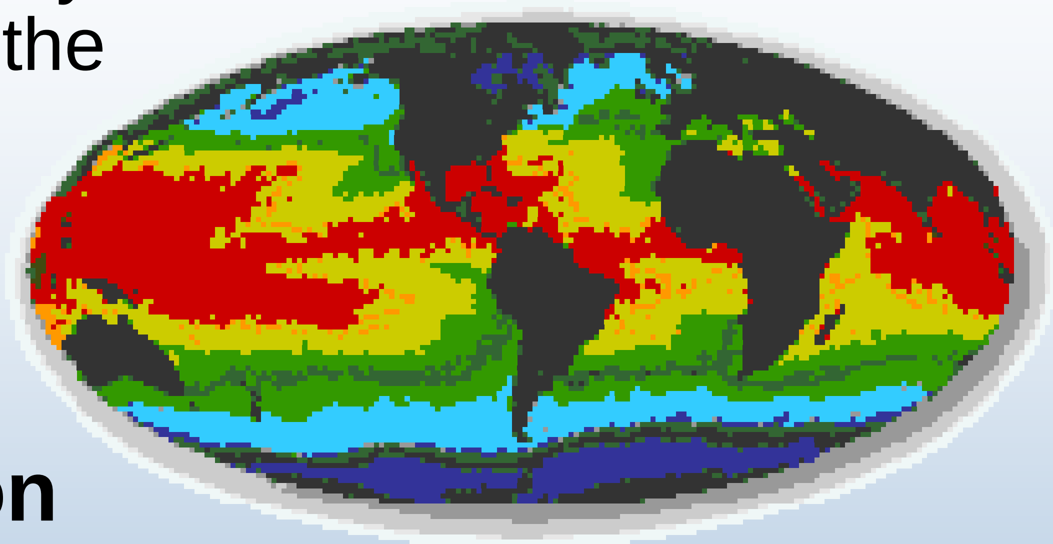
*Total economic impact includes direct, indirect and induced impacts.

Finances and Incentives

- Production Tax Credit
  - 1.9 cents/kWh (escalating) for 10 years equates to around 1.1 cents/kWh reduction in contract price
  - deadline pressure *increases* costs
  - Causes start/stop cycle
- State and Local tax, etc. can be significant
  - +/- 0.5 cents/kWh impact
- Public Power – regulated states – becomes part of their base rate and guaranteed profit
- Renewable Energy Production Incentive
  - annual appropriations problem leads to little impact
- Renewable Portfolio Standards
  - In Place in 22 States + DC

What is Wind Power?

•Wind energy is created by uneven solar heating of the earth



© 1998 www.WINDPOWER.org

Basic Wind Equation

Sun warms land mass + hot air rises + cooler air rushes in to take the place of the vacated air **=** ***wind***

Wind energy is kinetic energy -- mass and momentum

Derived from K.E. = $\frac{1}{2} mv^2$

$$P = A \times \rho V^3/2$$

– P = Power of the wind [Watts]

– A = Windswept area of rotor (blades) = $\pi D/4 = \pi r^2$ [m^2]

– ρ = Density of the air [kg/m^3] (at sea level at 15°C)

– V = Velocity of the wind [m/s]

Wind energy is proportional to velocity cubed (V^3):

–If velocity is doubled, power increases by a factor of eight ($2^3 = 8$).

–Small differences in average speed cause big differences in energy production.

Wind Resource Assessment

3 sites – all with 6.3 m/s wind at 10m

- Average annual wind power:

  220 W/m^2

  285 W/m^2

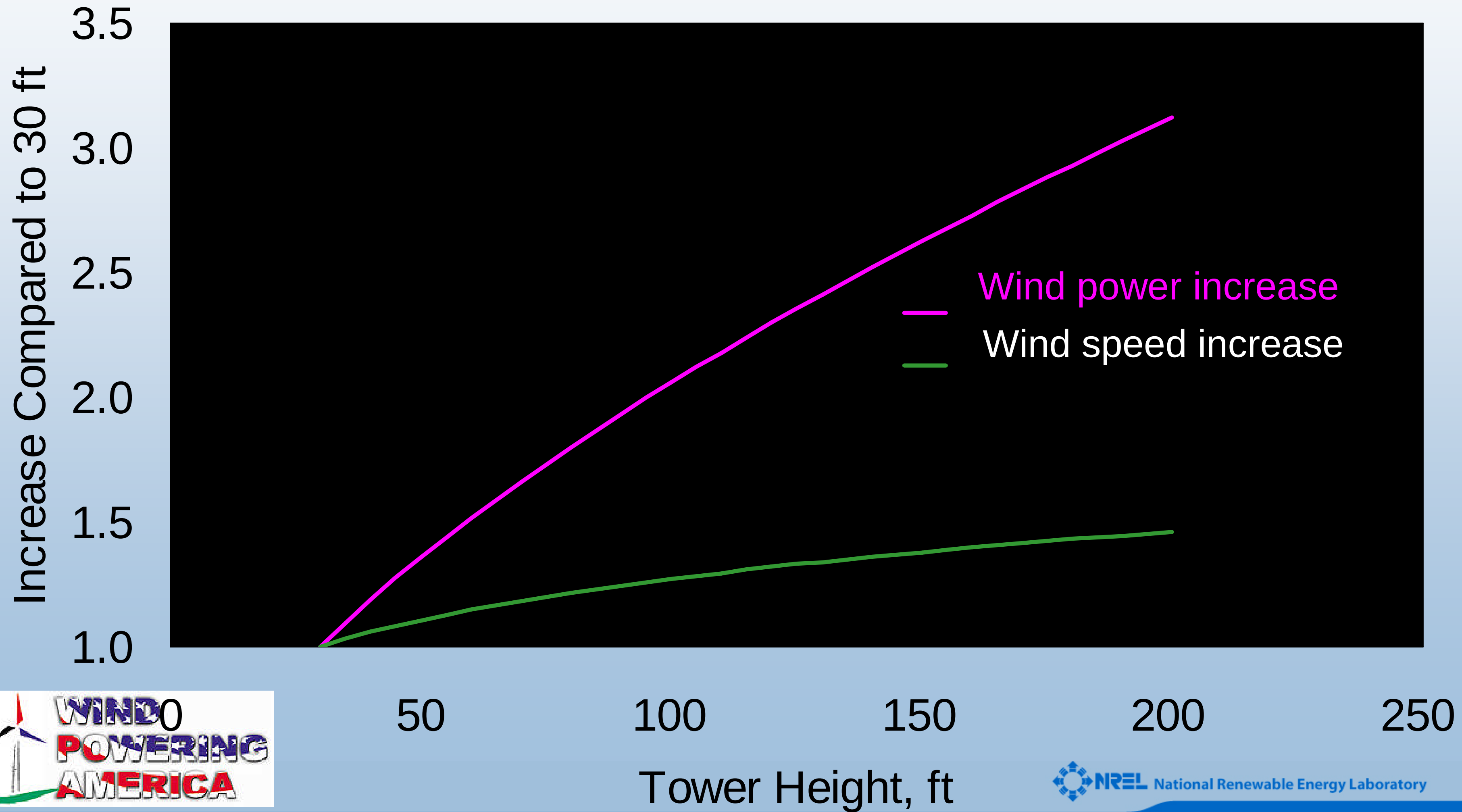
  365 W/m^2

  Varies by over 2 Wind Classes !

  The actual data matters

  – not just annual wind speed !

Wind Speed and Power Increase with Height Above the Ground



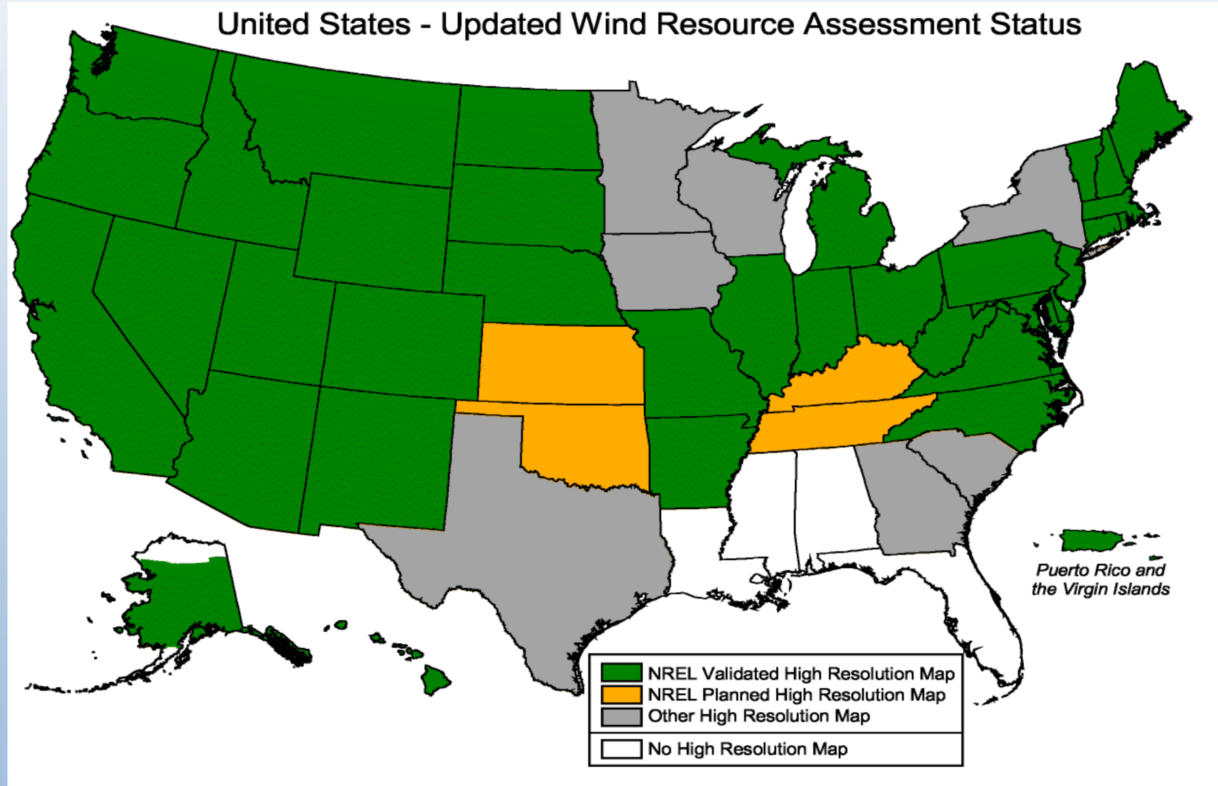
Relative Size of Swept Area

$A = Pi\ D^2 / 4$

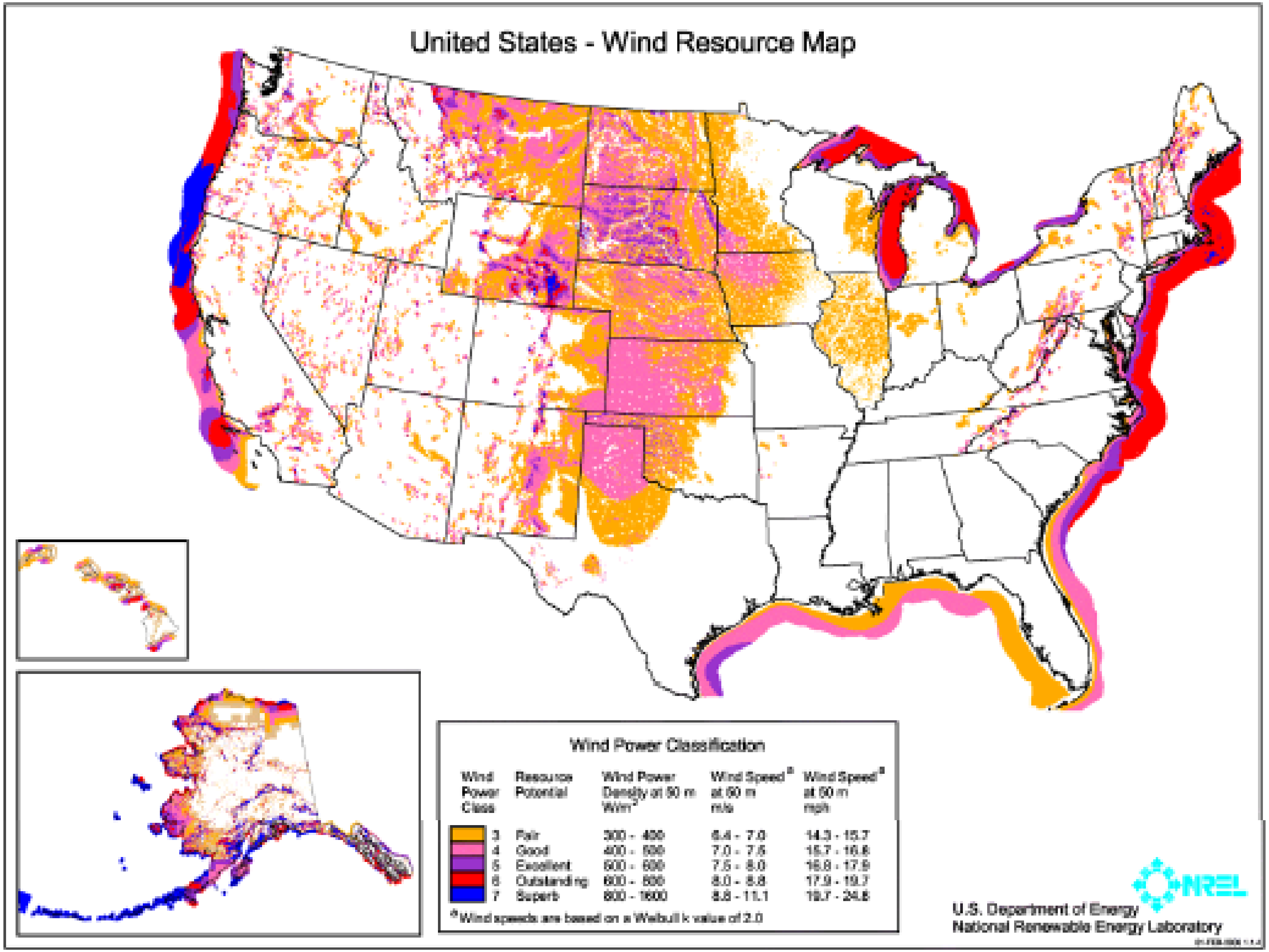
Credit: Paul Gipe

Wind Mapping and Validation

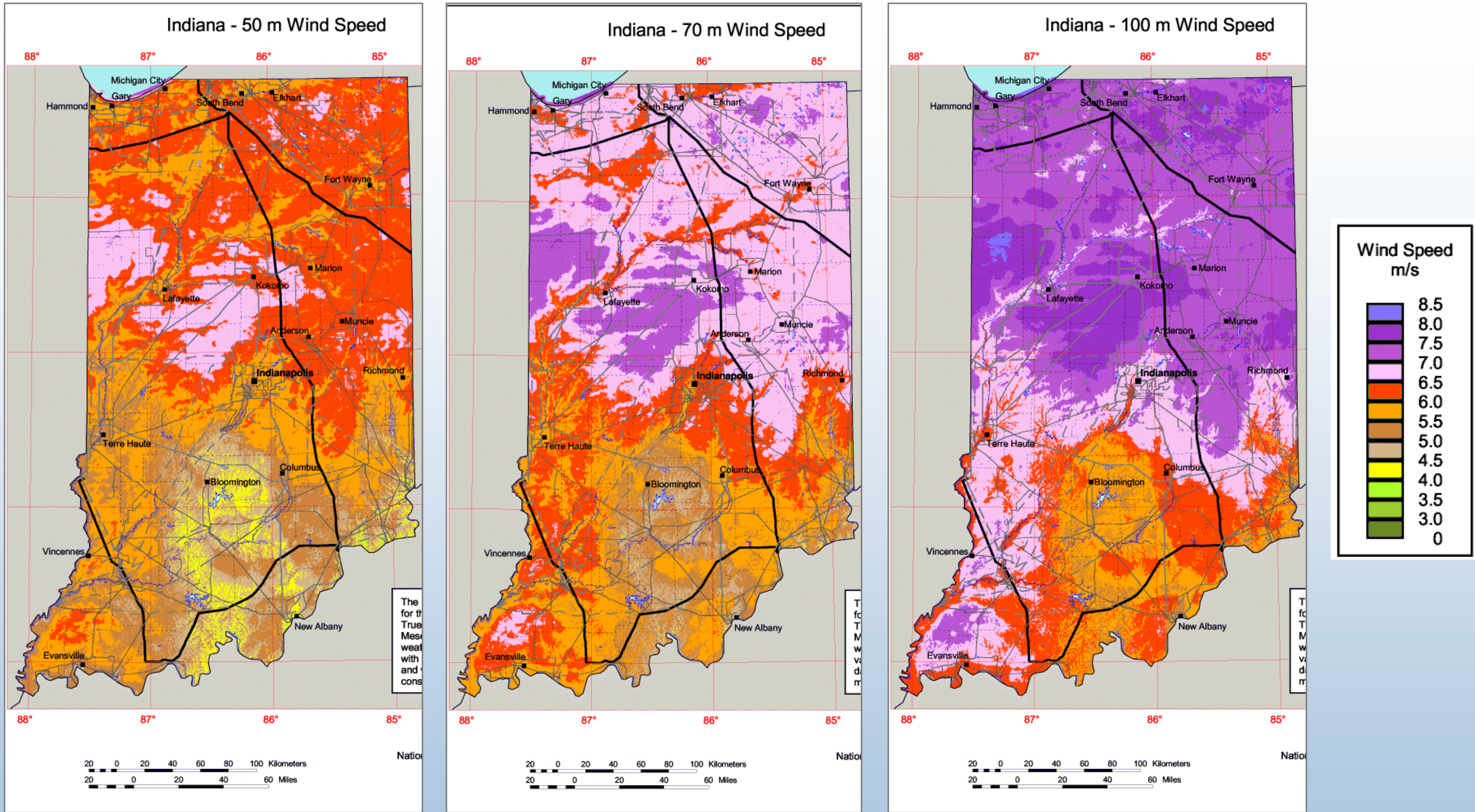
- 50m Validated Maps: 37 completed, KY, KS, TN, OK in '08
- Funding –jointly by DOE/NREL, states, and other organizations
- Other Participating Organizations
  - AWS Truewind: lead modeling consultant
  - Private consultants proprietary data used for NREL validation
  - State Offices/ Organizations



U.S. Wind Map


United States - Wind Resource Map
Wind Power Classification
Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m² | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb 800 - 1600 8.8 - 11.1 19.7 - 24.8
[a] Wind speeds are based on a Weibull k value of 2.0
NREL
U.S. Department of Energy
National Renewable Energy Laboratory

Providing Validated Wind Resource Maps at Modern Wind Turbine Hub Heights



Best areas 6.5-7 m/s
Capacity factors 30-35%

Best areas 7-7.5 m/s
Capacity factors 35-40%

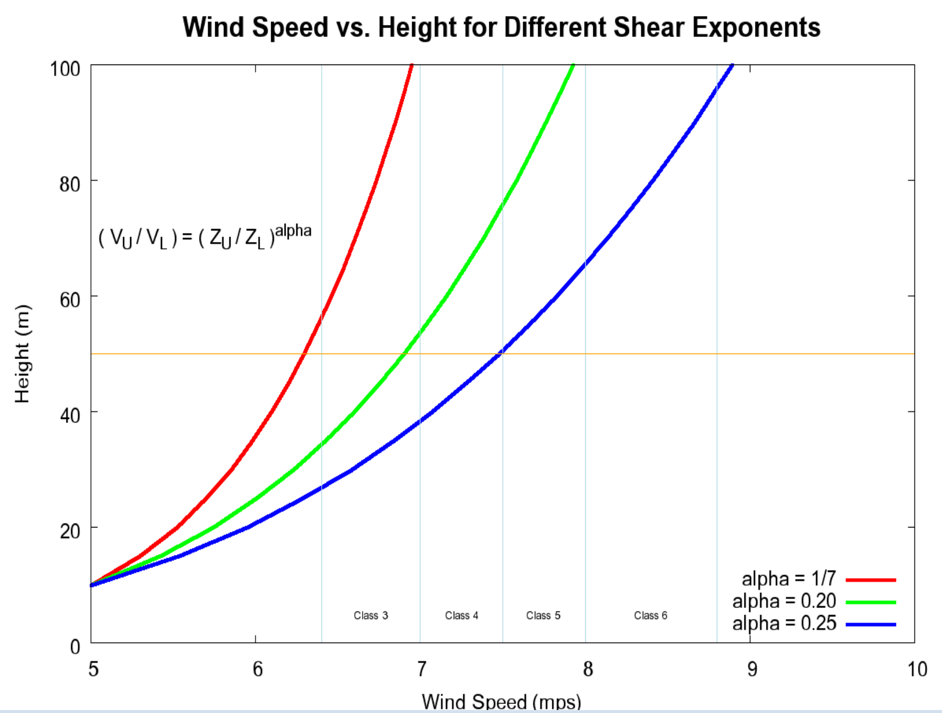
Best areas 7.5-8.2 m/s
Capacity factors 40-45%

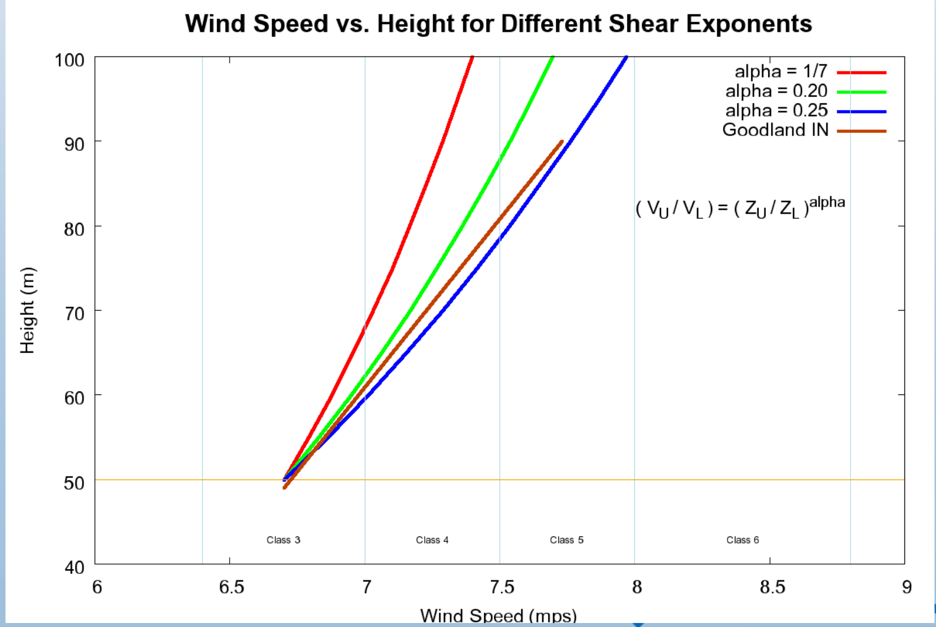
Wind resource data at 90-100m tower height revealed a significant increase in wind resources that helped jump start the state’s wind industry development.

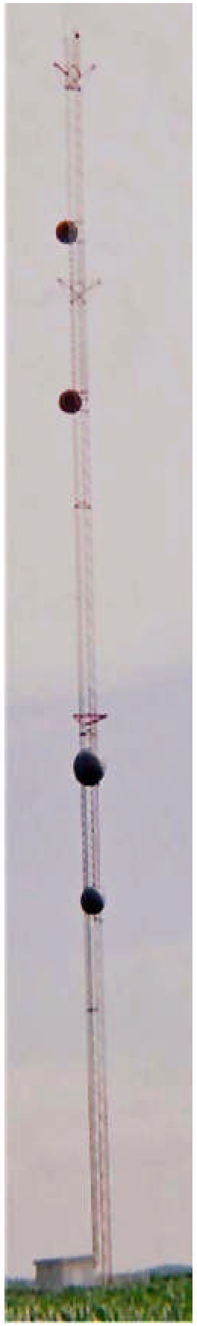
Shear exponents can vary from 1/7 (0.143) to 0.25+ → uncertainty in vertical extrapolation from lower heights

Tall tower and remote sensing measurements → high- confidence validated maps and model data for 70-100 m

The shear exponent from a tall tower at Goodland IN is 0.235 →significantly higher wind resource at 90 m than estimated







Validation of 70-100m maps and mesoscale model data

Tall towers - most reliable source of measurement data from 70 m and higher

Existing tall towers → least-cost validation data

Expensive → unless using existing tall towers

LIDAR - detects back-scattered light.

Measure wind higher than tall towers.

Expensive but data quality is high

SODAR - detects back-scattered sound.

Measure wind higher than tall towers but lower data recovery.

Supplement to tall tower, not replacement.

Potential use ->validation.

US Offshore Wind Mapping Objectives

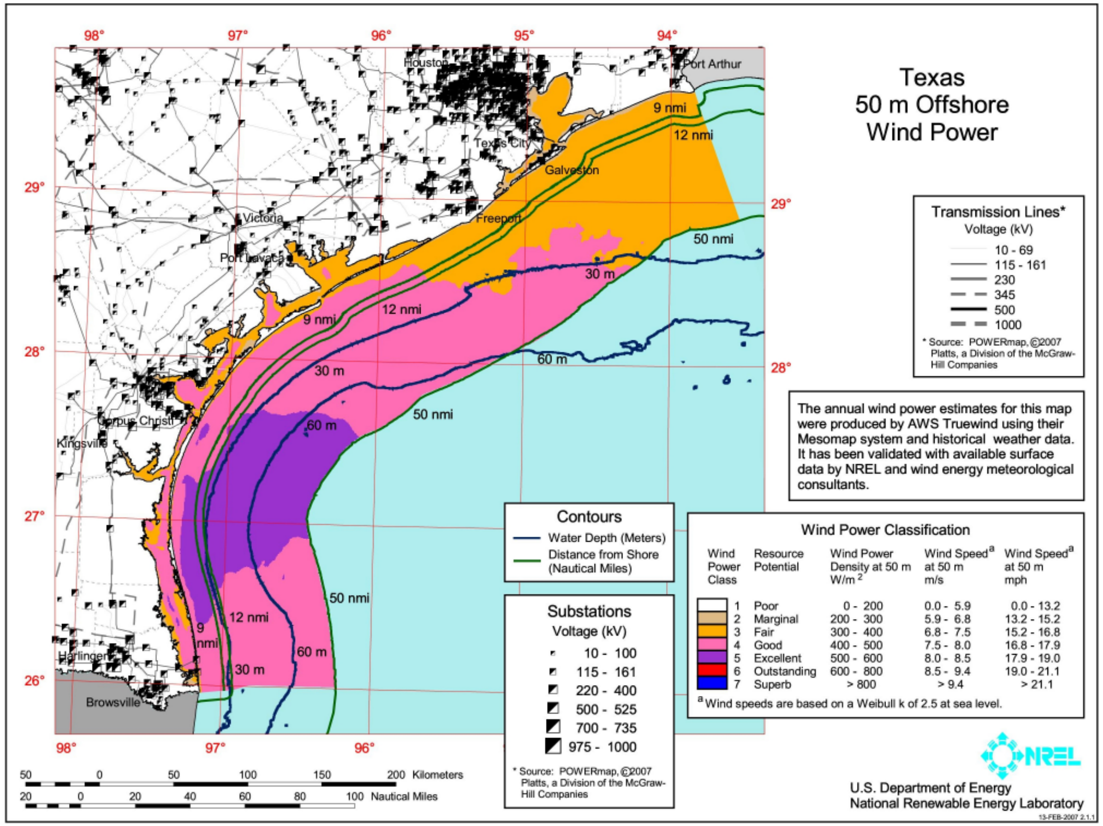
Develop high-resolution validated wind resource maps

- Ocean regions: coast to 50 nautical miles offshore
- Great Lakes: entire surface

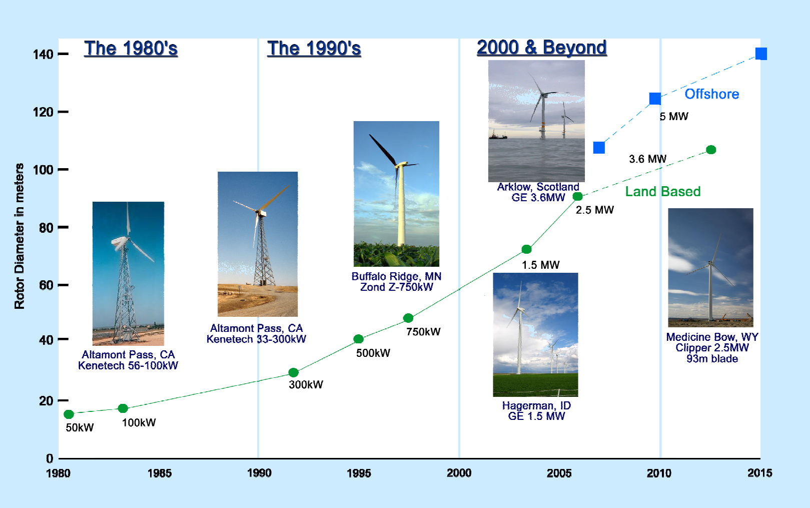
Project jointly funded by DOE/NREL, states, other organizations

Priority offshore regions:

- Great Lakes
- Eastern coast areas from Maine to northern Florida
- Western Gulf of Mexico (Texas and Louisiana)



Change is in the Wind



Primary Focus: Creating Viable Options

Metric: Cost of Energy

THEN

NOW

Primary Focus: Enabling Deployment and Production of Wind Energy at Scale (20% Vision)

Metrics: Reliability & Performance

20% Wind Scenario Challenges:

- Transmission and grid integration
- Siting and environmental issues/technology acceptance
- Reliability, standards, test facilities
- Reduce cost and improve performance
- Advanced manufacturing– create sustainable, competitive US jobs
- Workforce development

Wind Powering America Strategy

Goal: By 2010, at least 100 MW installed in 30 states

(2000 Goal: 24 states with 20 MW by 2010)

Annual Goals/Actuals

Year	> 100 MW	Actuals*
< 2005	12	12
2005	16	16
2006	19	16
2007	20	17
2008	22	*25*
2009	27	*30*
2010	30	*35*

*Actuals through 2007

Thematic Areas

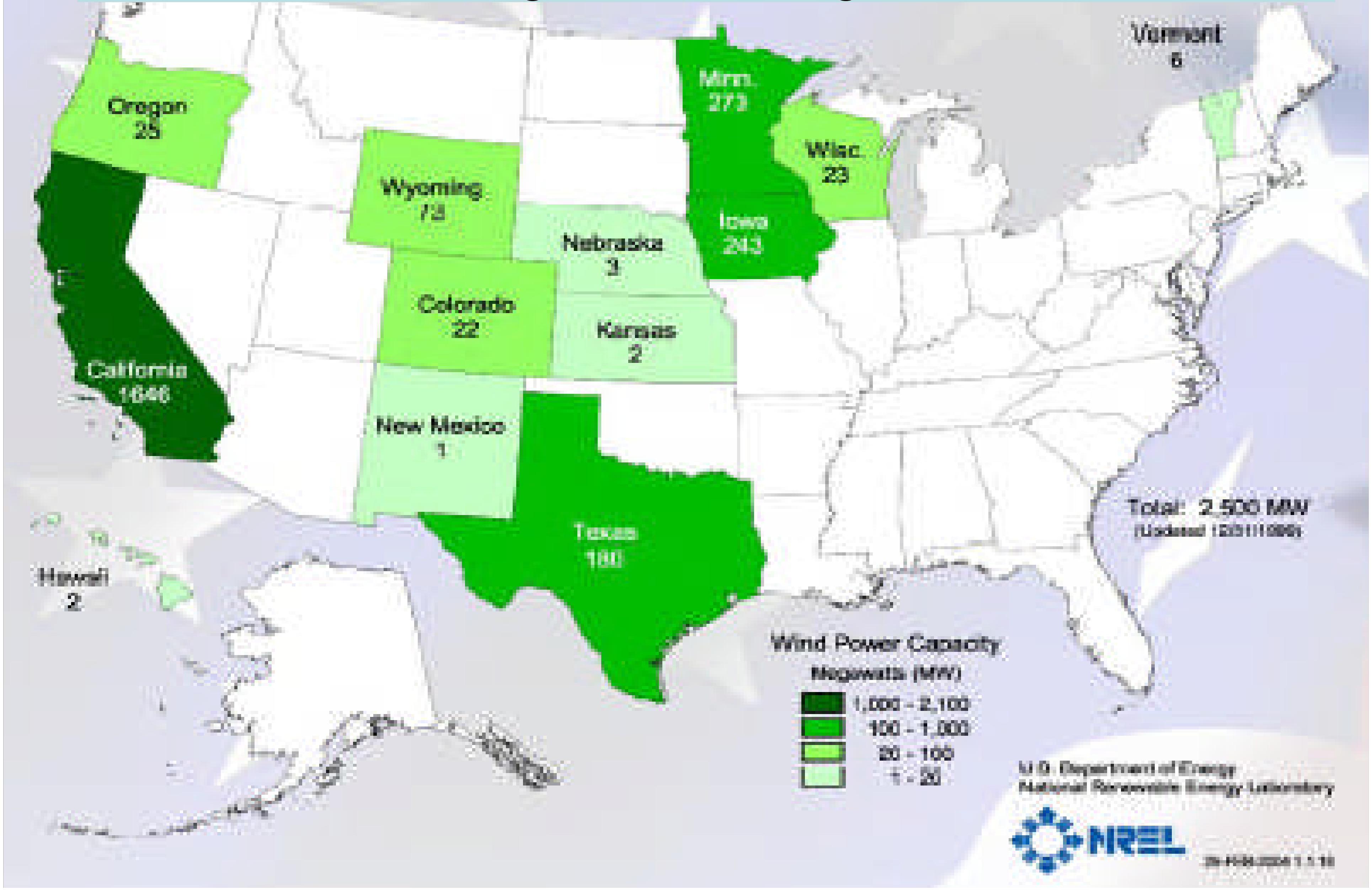
- State Wind Support
  - Wind Working Groups
  - Stakeholder Outreach
  - Economic Development
  - Wind Mapping
- Priority Markets
  - Public Power
  - Native America
  - Distributed (Small) Wind
  - Wind for Schools
  - Federal Loads

State Wind Working Groups*

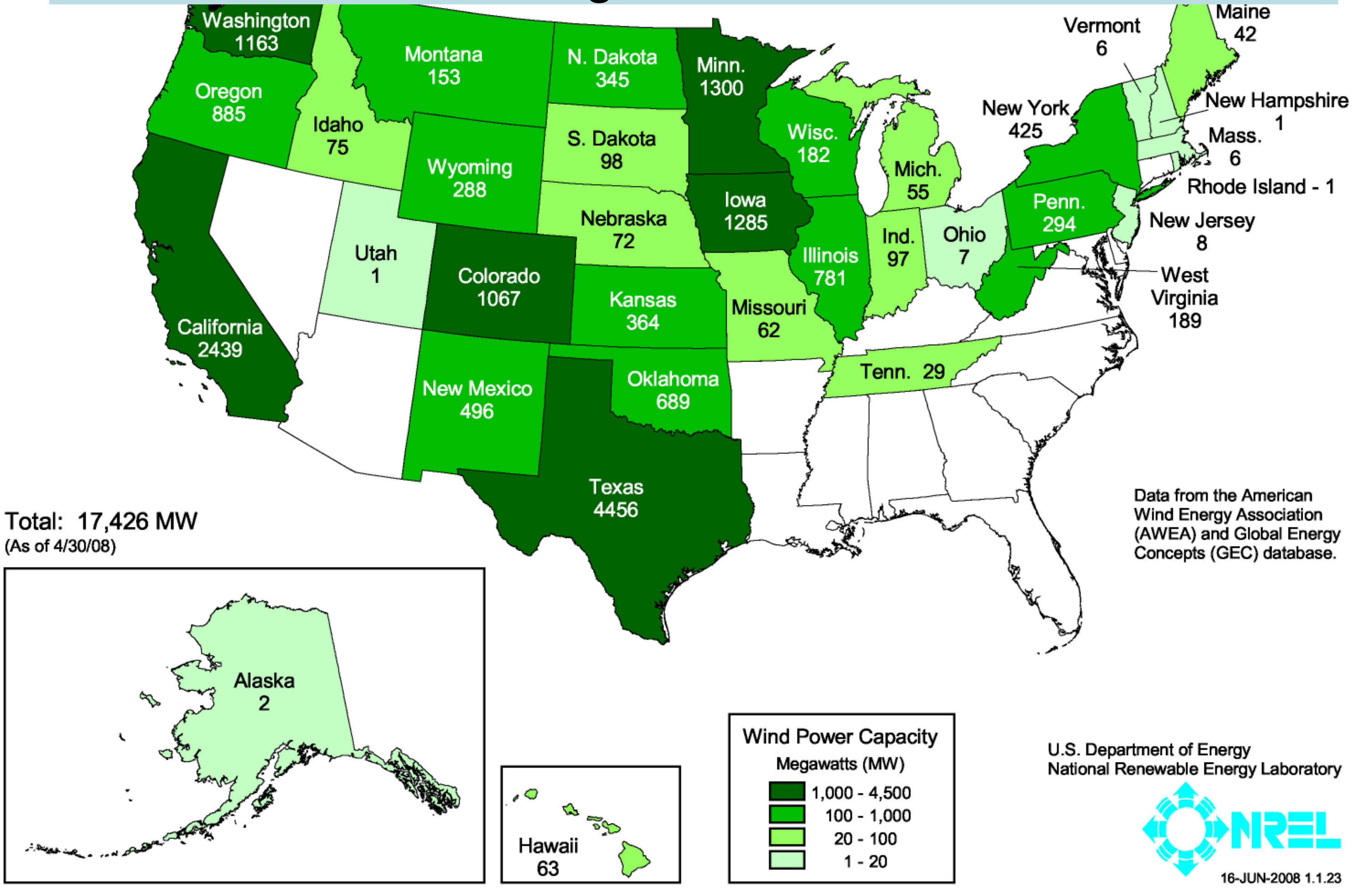
- Alaska
- Arizona
- Arkansas
- Colorado***
- Connecticut
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Kansas
- Maine**
- Maryland
- Massachusetts
- Michigan
- Missouri
- Montana
- Nebraska
- Nevada
- New Jersey
- New Mexico
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Puerto Rico**
- South Dakota
- Tennessee
- Utah
- Virginia
- Washington***
- West Virginia
- Wisconsin
- Wyoming

*Red – Priority State
*Green– Medium Priority State
** - WWG in formative stage
*** - WWG being reformulated

State-by-state wind capacity (MW) when Wind Powering America began - 1999



State-by-state wind capacity (MW) when Wind Powering America - 2007



A New Vision

For Wind Energy in the U.S.

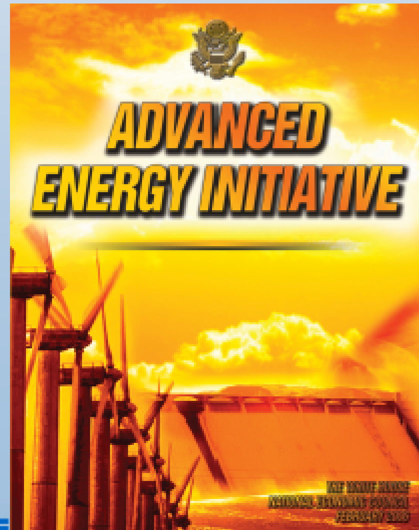
White House photo by Eric Draper

State of the Union Address

"…We will invest more in … **revolutionary** and solar **wind technologies**"

Advanced Energy Initiative

"Areas with good wind resources have the potential to **supply up to 20% of the electricity** consumption of the United States."



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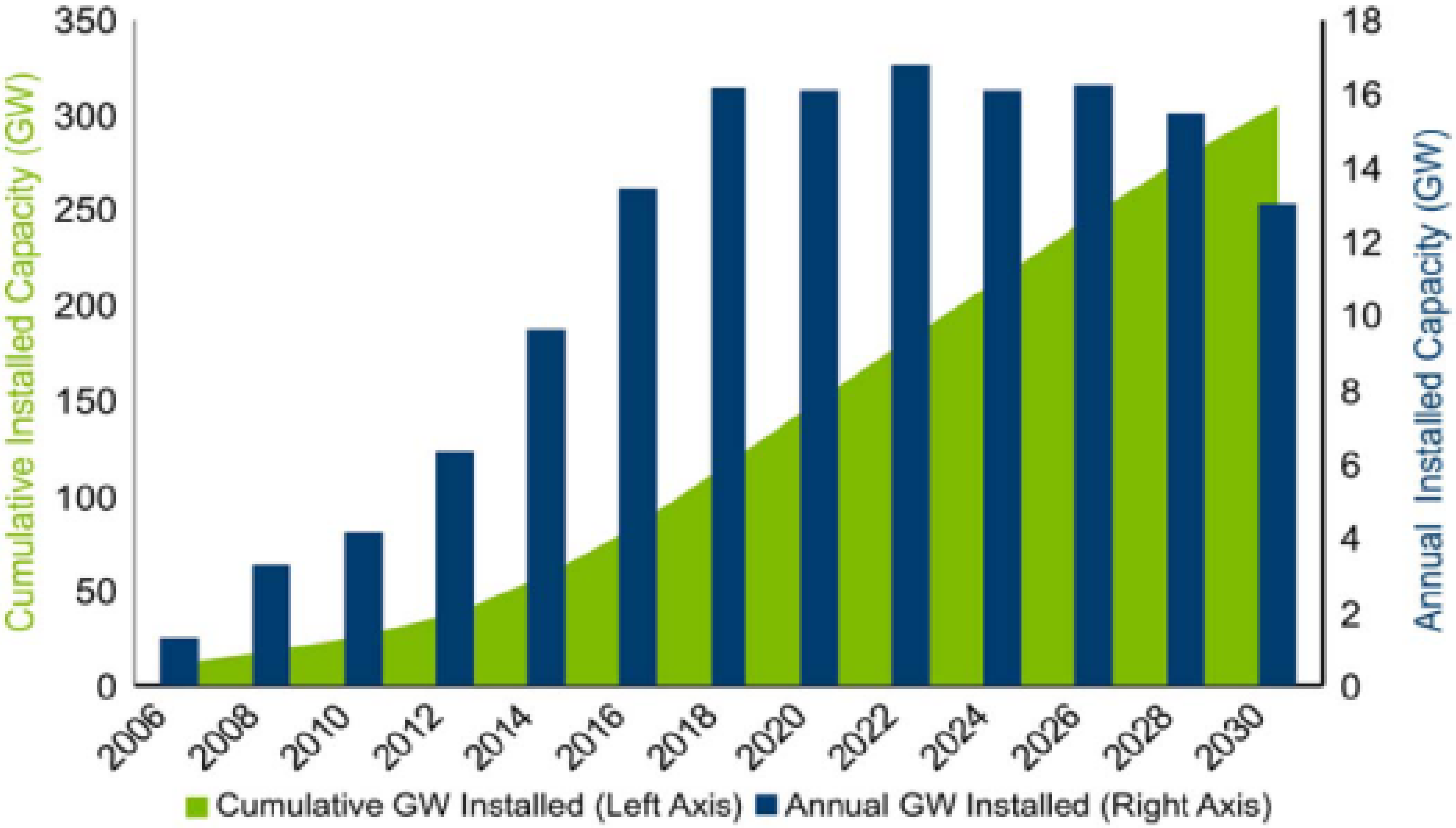
What does 20% Wind look like?

Figure 1-4. Annual and cumulative wind installations by 2030



Source: DOE 20% Report

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20% Market Barriers

- National and state policy uncertainty (PTC, RPS, C)
- Mixed stakeholder perspectives and knowledge
- Electricity supply planning based on capacity
- Variable wind output viewed as unreliable
- Incomplete comparative generation assessments
- Mismatch of wind and transmission development timeframes
- Lack of interstate approach to transmission development
- Federal lending all-requirements contracts for G&Ts
- High cost and low turbine availability for community projects
- High cost and permitting challenges of <1 MW turbines

Panel Proposed Framework to Address 20% Wind Priorities

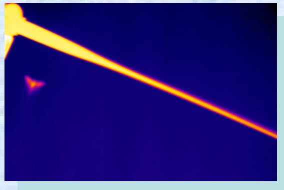
Technology

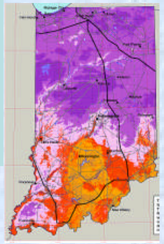
The Right Turbines

- Blades
- Tower
- Storage
- Software
- Components
- Standards
- Testing

Siting

In the Right Places





- Resources
- Land Use
- Environmental Interface

Systems Integration

Integrated and Operating Effectively in the Electricity System

- Transmission Planning
- Grid Interface
- Storage Use
- Capacity Utilization
- Reliability

Policy

- Mandates
- Incentives

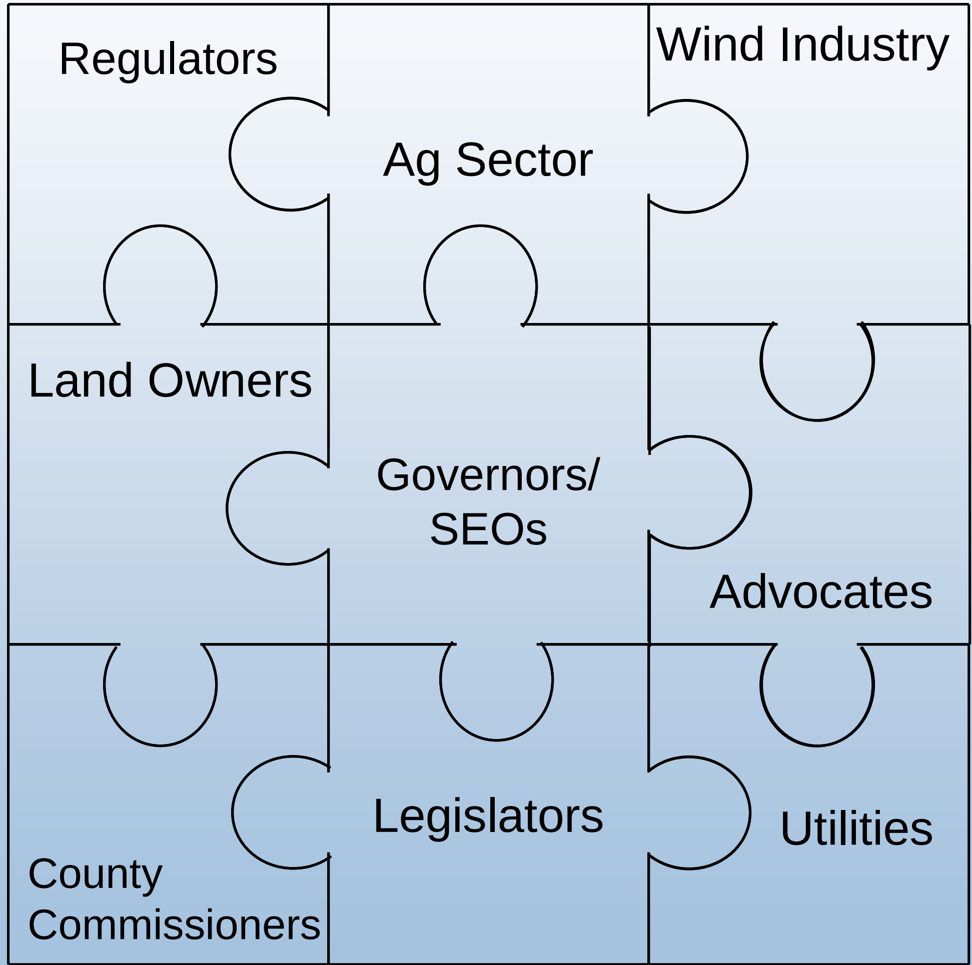
Education

- Federal
- State
- Communities
- School Programs

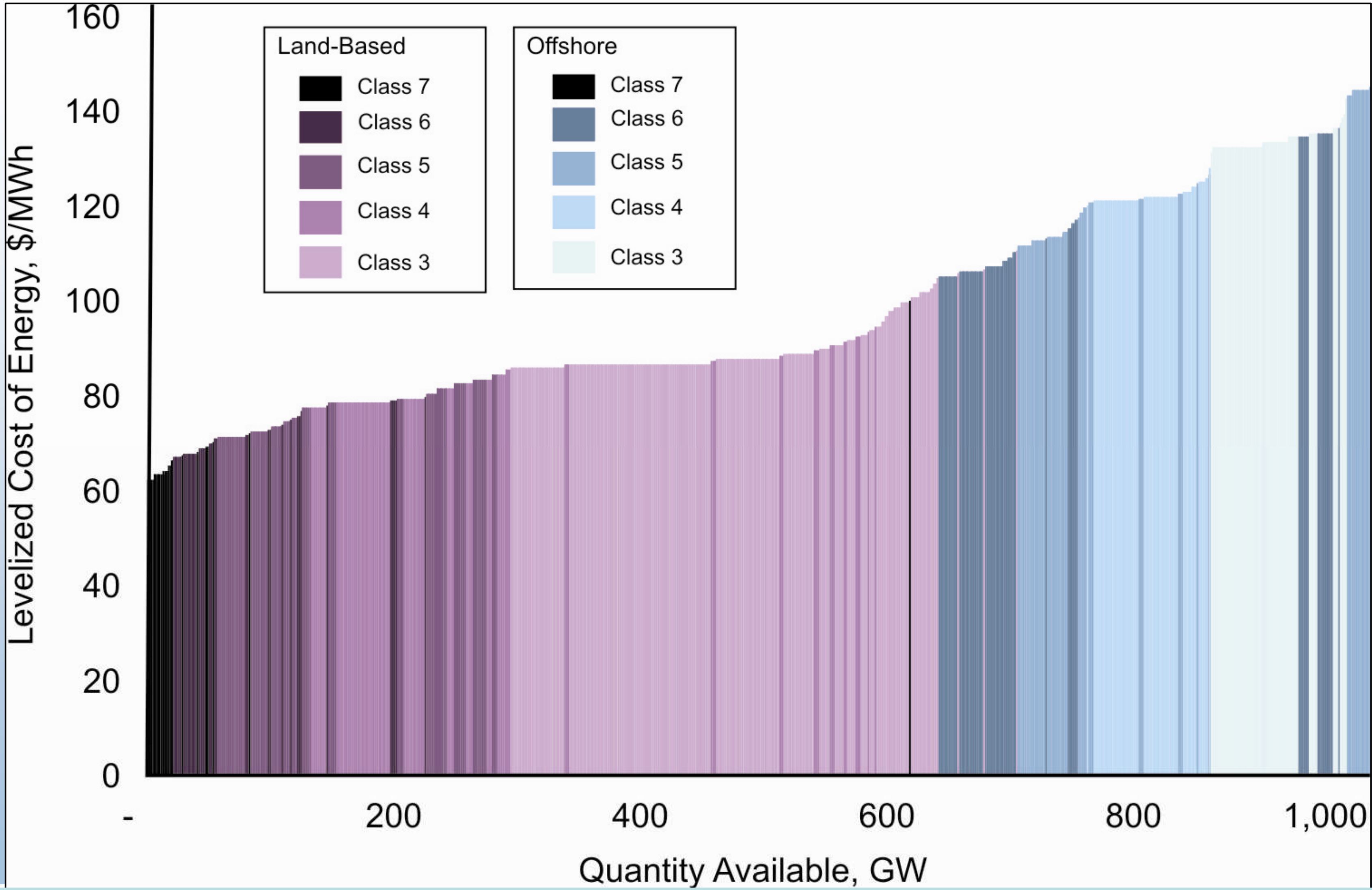
Workforce

- R&D
- Manufacturing
- Construction
- O&M

Wind Stakeholders



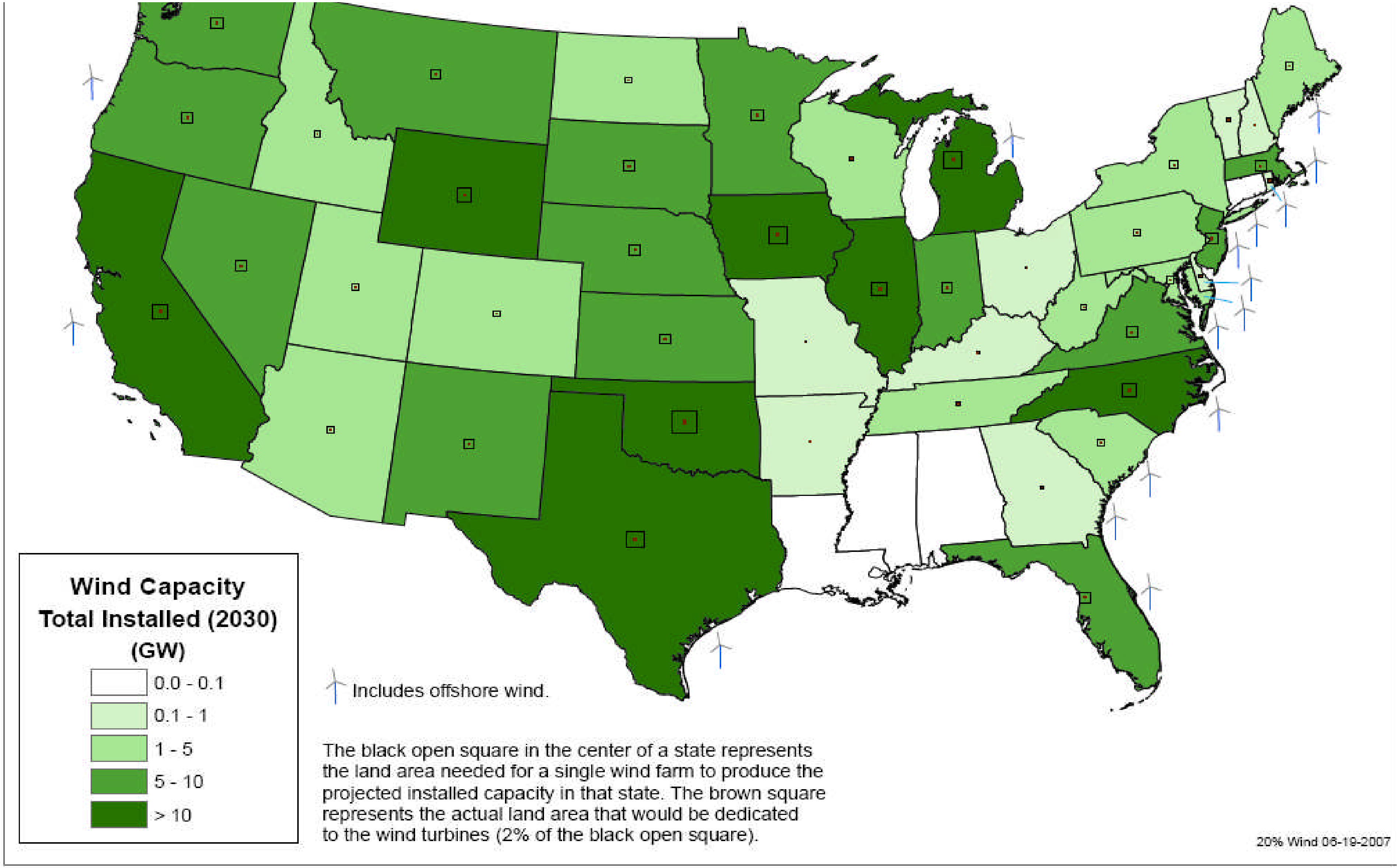
Wind Energy Supply Curve



Excludes PTC, includes transmission costs to access 10% existing electric transmission capacity within 500 miles of wind resource.

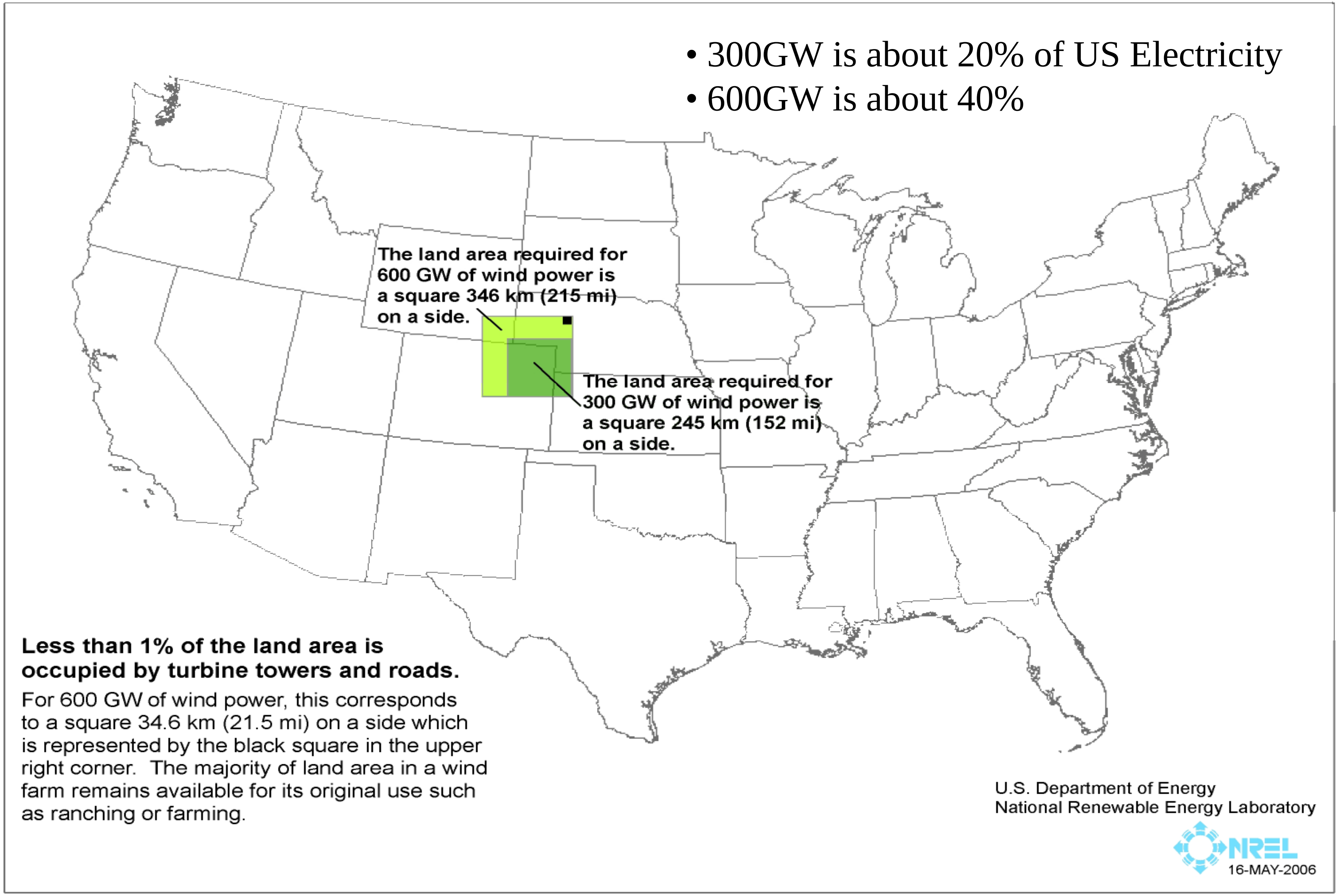
Installed Wind Capacity by 2030

to Reach 20% Wind



Land Requirements for 20% of the Nations Electricity

- 300GW is about 20% of US Electricity
- 600GW is about 40%



Conceptual Map of How to Get There - Transmission

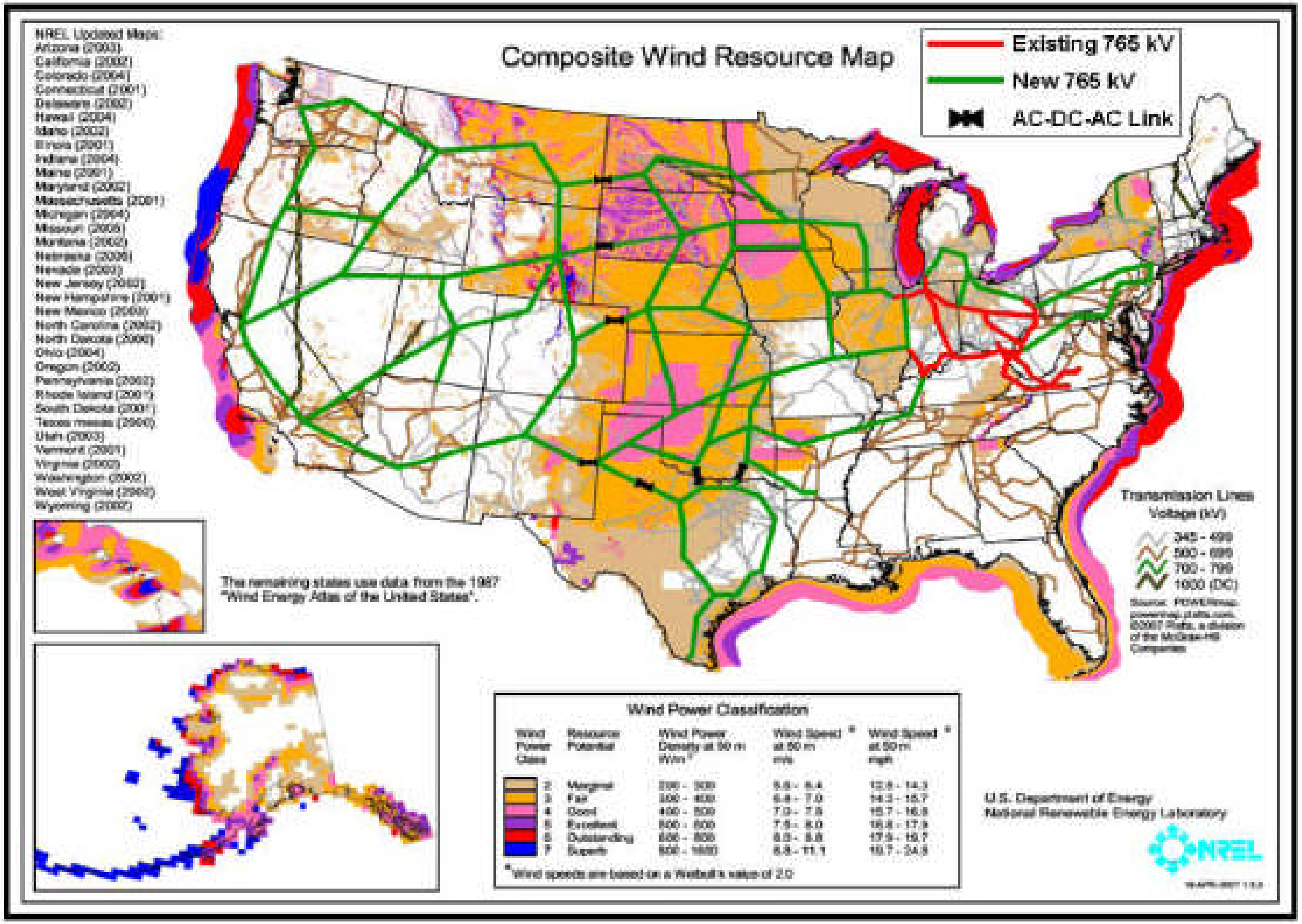
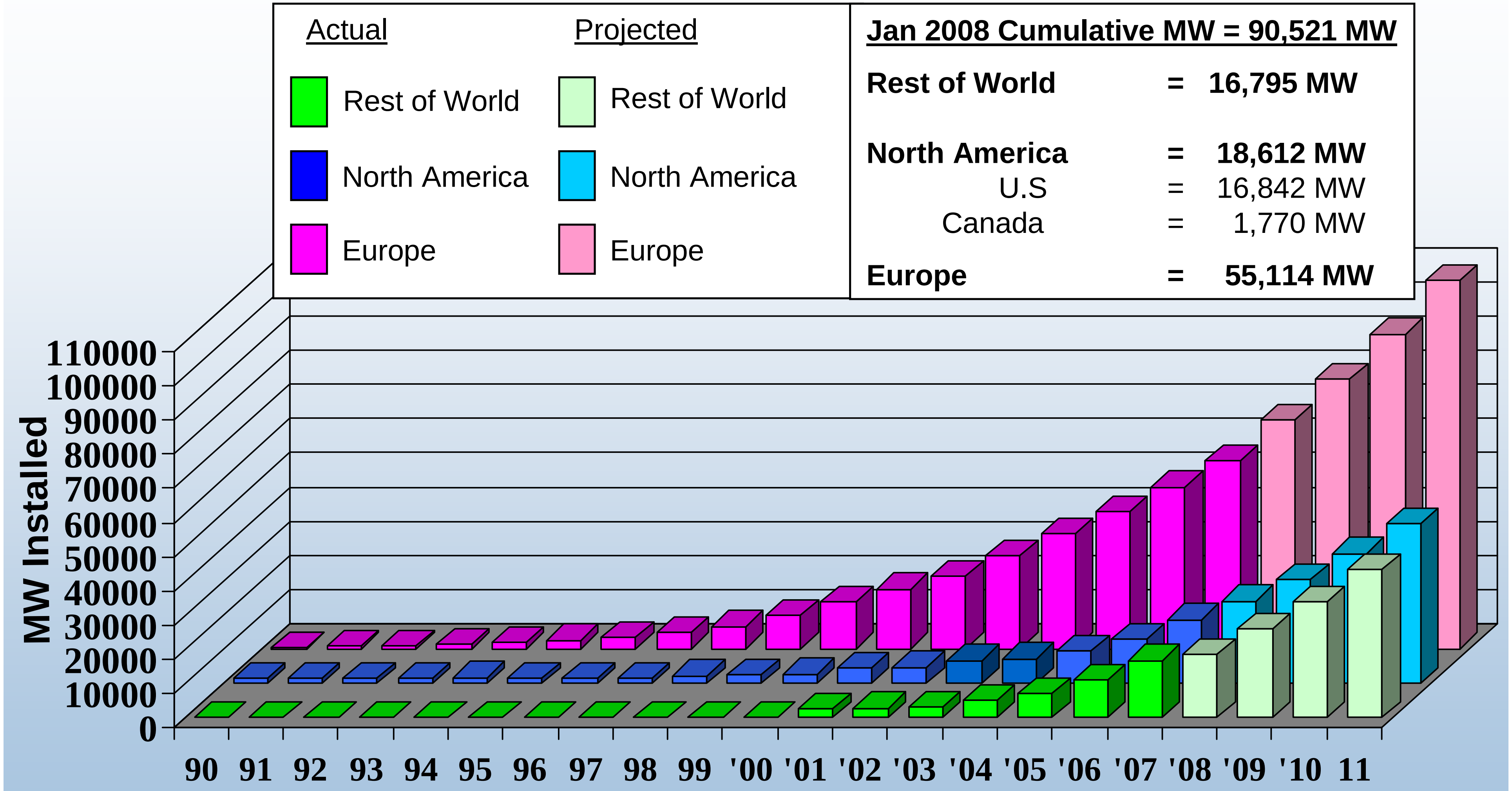


Exhibit 1: Conceptual 765 kV backbone system for wind resource integration (edited by AEP).

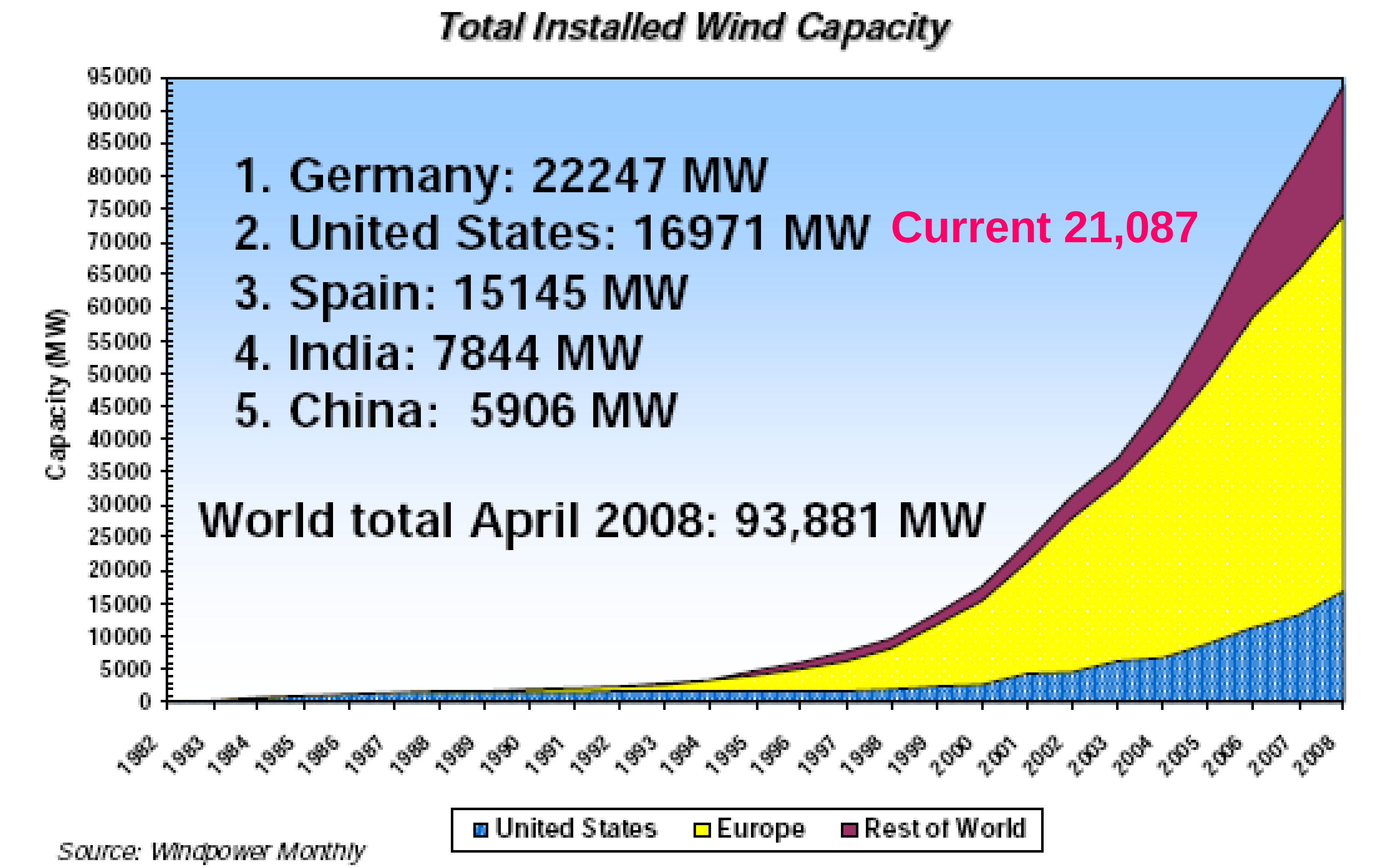
Growth of Wind Energy Capacity Worldwide



Sources: BTM Consult Aps, March 2007
Windpower Monthly, January 2008
*NREL Estimate for 2008

NREL National Renewable Energy Laboratory

Who is Doing Wind?



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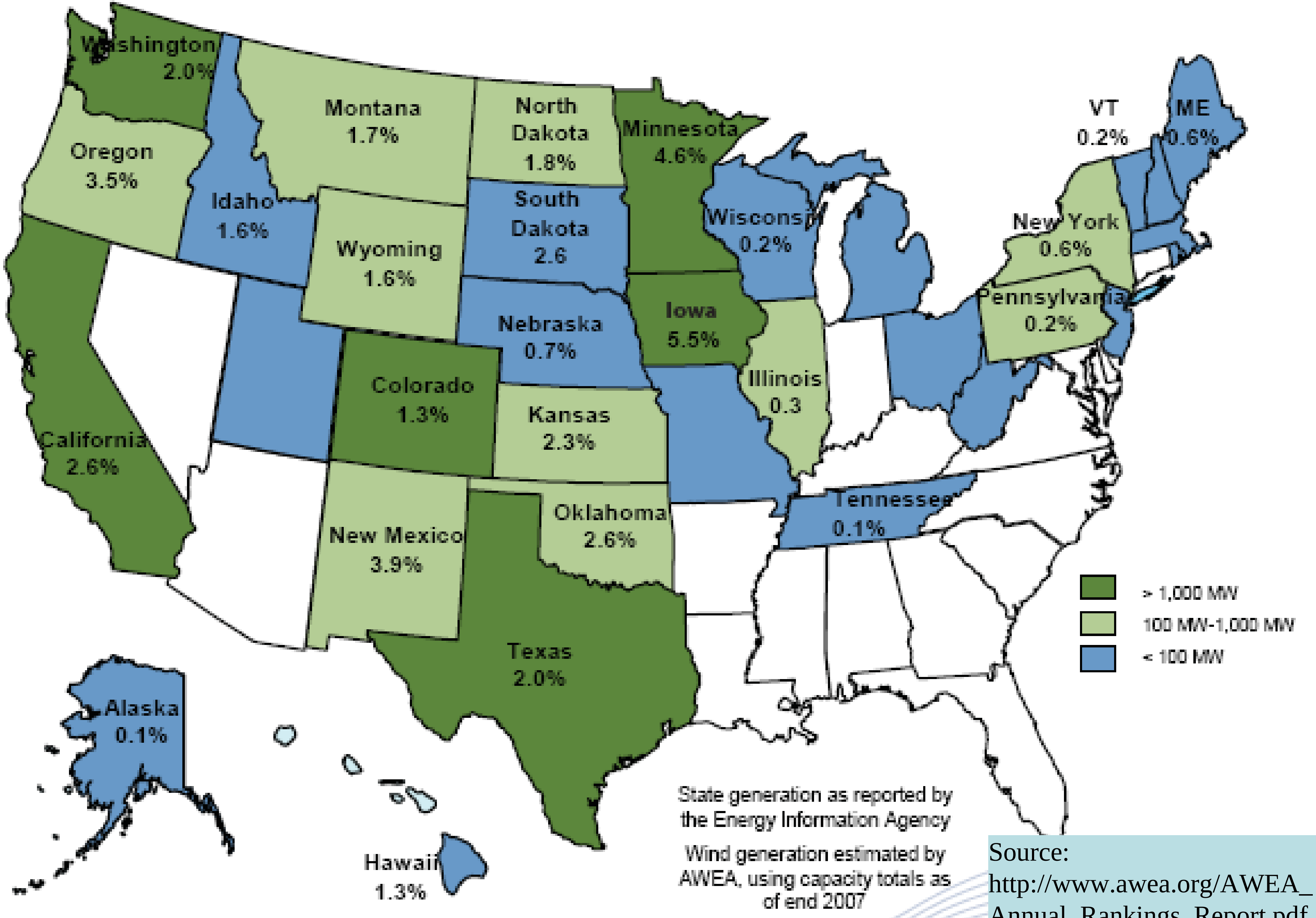
U.S. Led the World in 2007 Wind Capacity Additions; Second in Cumulative Capacity

Incremental Capacity (2007, MW)		Cumulative Capacity (end of 2007, MW)	
U.S.	**5,329**	Germany	22,277
China	3,287	**U.S.**	**16,904**
Spain	3,100	Spain	14,714
Germany	1,667	India	7,845
India	1,617	China	5,875
France	888	Denmark	3,088
Italy	603	Italy	2,721
Portugal	434	France	2,471
U.K.	427	U.K.	2,394
Canada	386	Portugal	2,150
Rest of World	2,138	*Rest of World*	13,591
TOTAL	**19,876**	**TOTAL**	**94,030**

Source: BTM Consult; AWEA project database for U.S. capacity.

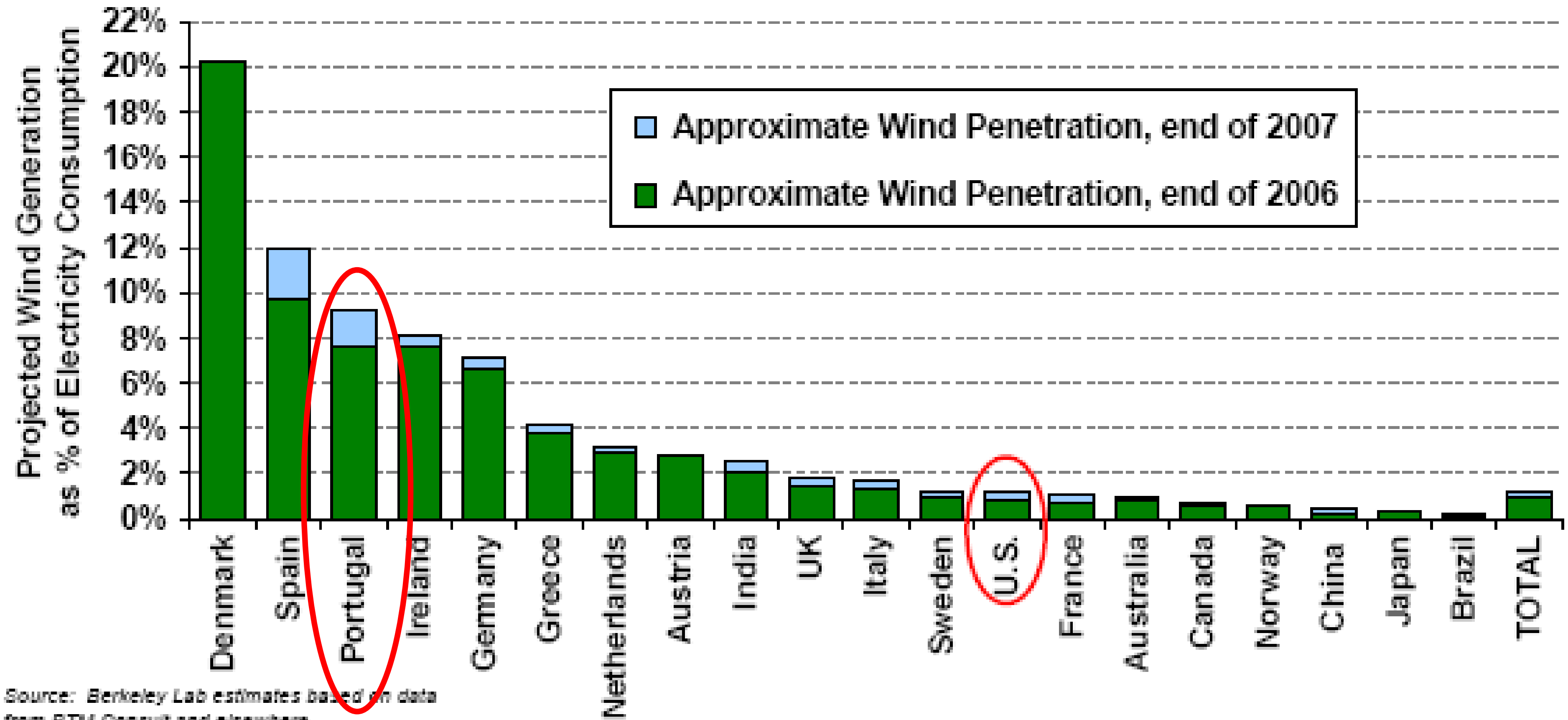
Percentage of State Electricity from Wind



Source: http://www.awea.org/AWEA_Annual_Rankings_Report.pdf

Wind – not just "How Many Installed MW?"

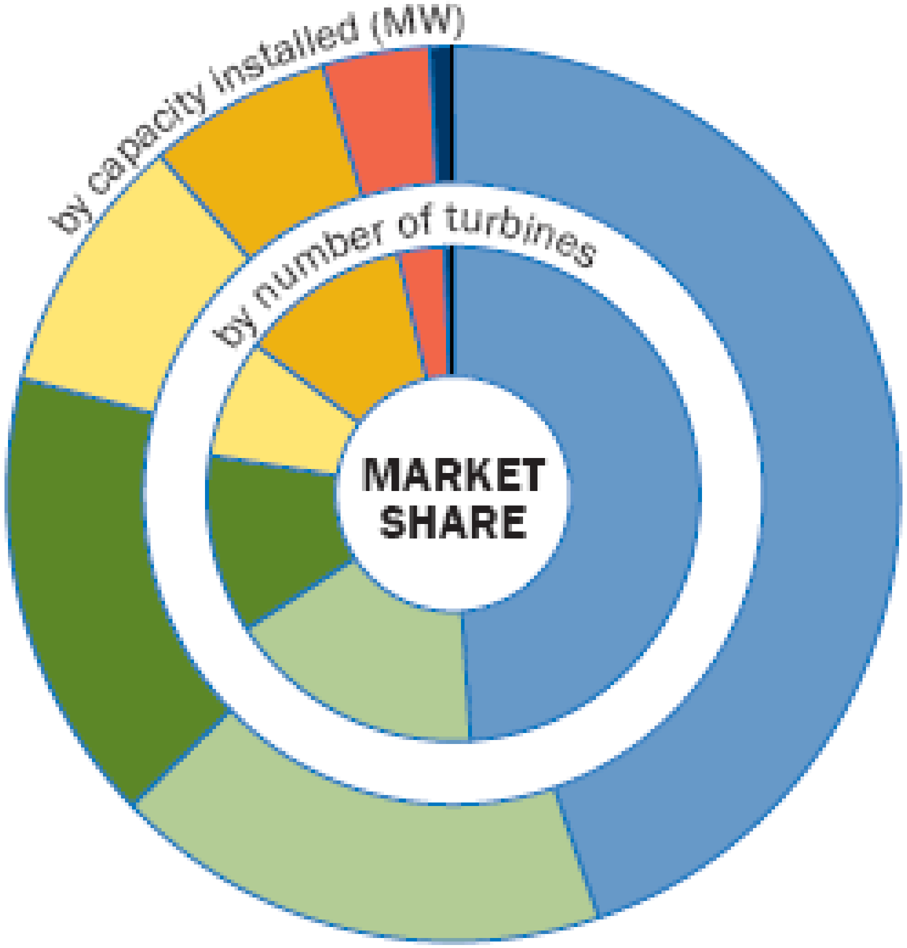
What Percentage of Energy is from Wind?



Source: Berkeley Lab estimates based on data from BTM Consult and elsewhere

Note: Figure only includes the 20 countries with the most installed wind capacity at the end of 2007

Major Wind Turbine Suppliers



Installed in 2007

Company	MW	Turbines
GE Energy	2,340	1,560
Vestas	953	537
Siemens	863	375
Gamesa	574	287
Mitsubishi Power Systems	356	356
Suzlon	197	97
Clipper	48	19
Nordex	2.5	1

Source: http://www.awea.org/AWEA_Annual_Rankings_Report.pdf

Major Wind Turbine Suppliers

Largest turbine manufacturers in 2007,
by installed capacity (MW) and number of turbines

Turbine Manufacturer	Capacity installed (MW)	Number of turbines
GE Energy	2,340	1,560
Vestas	953	537
Siemens	863	375
Gamesa	574	287
Mitsubishi	356	356

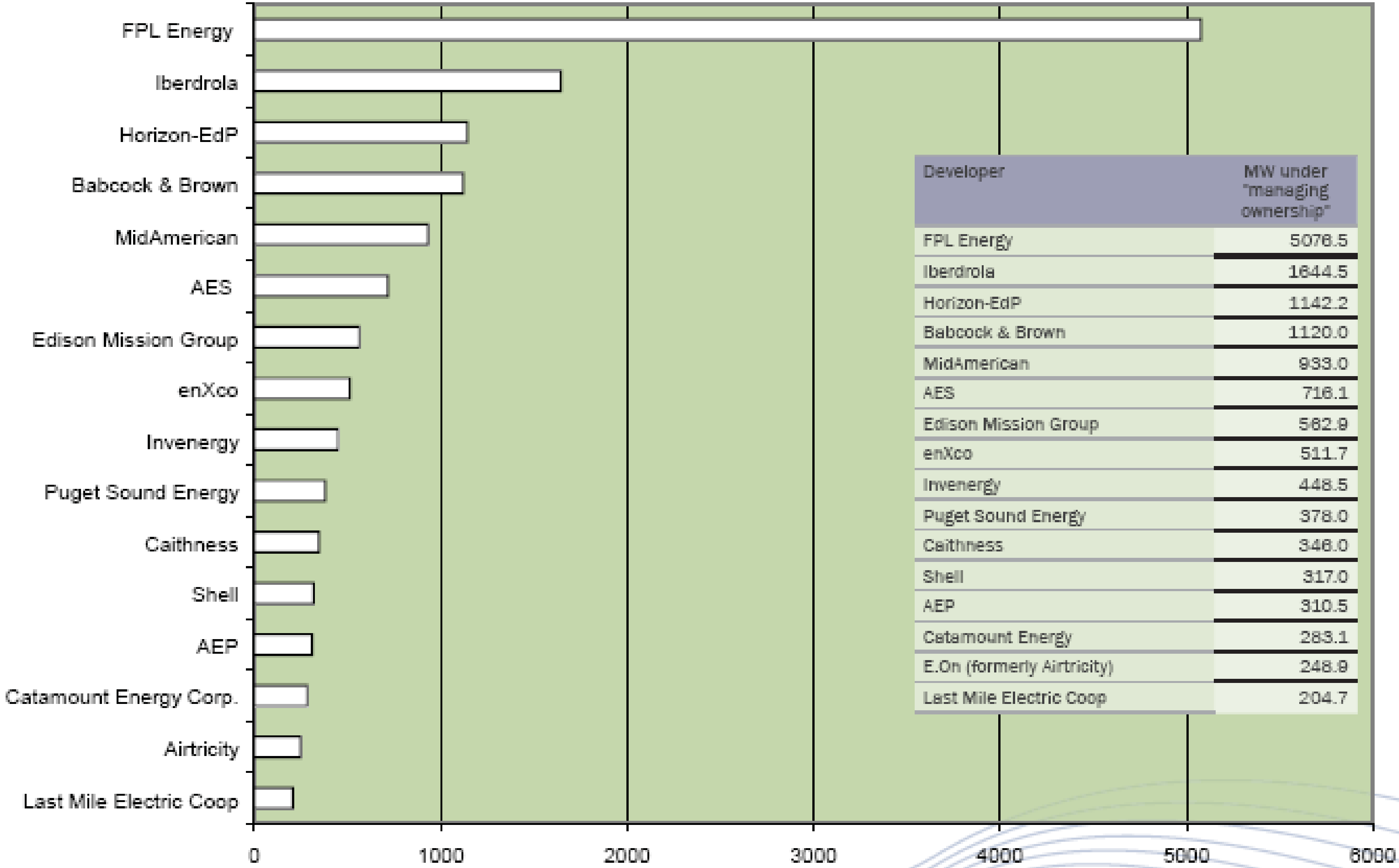
Largest wind turbines installed in the U.S.
(rated capacity, in MW)

Rated capacity (MW)	Turbine manufacturer	Locations installed
3	Vestas	CA, TX
2.5	Clipper, Nordex	IL, IA, MN, NY, WY
2.3	Siemens	MN, ND, OR, TX, WA
2.1	Suzlon	IA, MO, OK
2	Gamesa	CA, IL, IA, MN, PA, TX

These turbines stand 90 meters to 150 meters tall

Source:
http://www.awea.org/AWEA_Annual_Rankings_Report.pdf

Major Wind Farm Developers/Owners

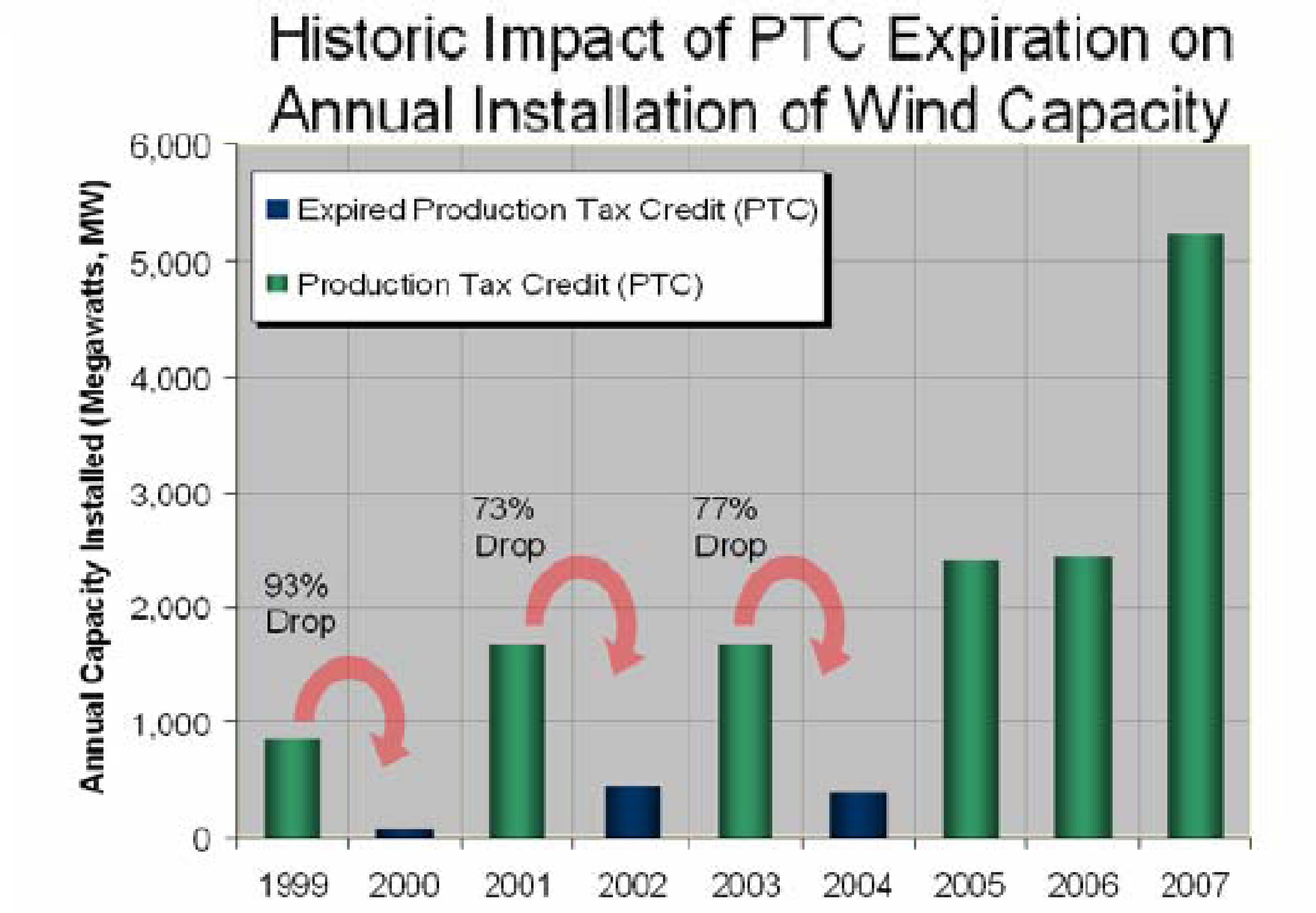


Developer	MW under "managing ownership"
FPL Energy	5076.5
Iberdrola	1644.5
Horizon-EdP	1142.2
Babcock & Brown	1120.0
MidAmerican	933.0
AES	716.1
Edison Mission Group	562.9
enXco	511.7
Invenergy	448.5
Puget Sound Energy	378.0
Caithness	346.0
Shell	317.0
AEP	310.5
Catamount Energy	283.1
E.On (formerly Airtricity)	248.9
Last Mile Electric Coop	204.7

Source: http://www.awea.org/AWEA_Annual_Rankings_Report.pdf

New Trend – MEGA Wind Farms

- 909MW - Shepherd's Flat OR (Caithness Energy)
- 4,000MW – Panhandle Mesa Power TX (T. Boone Pickens)
- 735MW - Horse Hollow (FPL)
- 5,050MW – Titan Project SD (Clipper and BP Energy Alternative) – 3,500MW is contiguous, bundled with 1,550MW
- 3,000MW – Briscoe County BTX (Shell WindEnergy and TXU)
- 2,000MW – Carbon County WY (Power Company of Wyoming - Anschutz)



Source: AWEA PTC Facts Sheet

Policy Drives Investment

2006 new wind-related manufacturing plants established in:

- Iowa (Clipper Windpower)
- Minnesota (Suzlon)
- Pennsylvania (Gamesa).
- And GE Energy, the most prominent U.S. wind turbine manufacturer, captured 47% of domestic wind turbine sales in 2006

2008

- Colorado (Vestas)

Sizes and Applications

Small (≤10 kW)

- Homes
- Farms
- Remote Application

Intermediate (10-250 kW)

- Village Power
- Hybrid Systems
- Distributed Power

Large (600 kW – 5 MW)

- **Central Station Wind Farms**
- Distributed Power
- Community Wind

Large Wind Turbines

- Towers: 80-120m
- Rotors: 80-120m
- Weight: 200-400 tons

Issues:

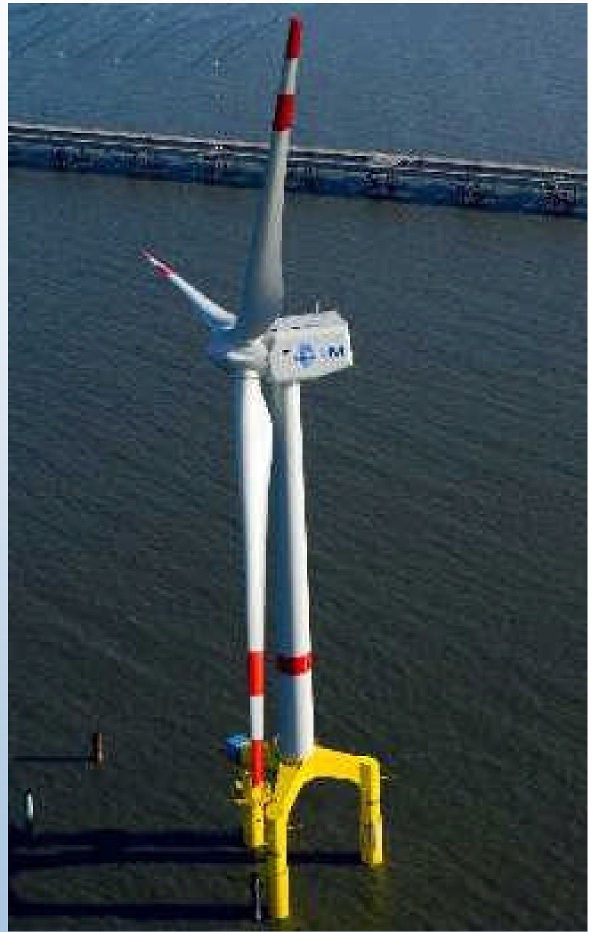
•Roads & bridges

•Cranes

Utility-Scale Wind Power

600 kW – 5 MW wind turbines

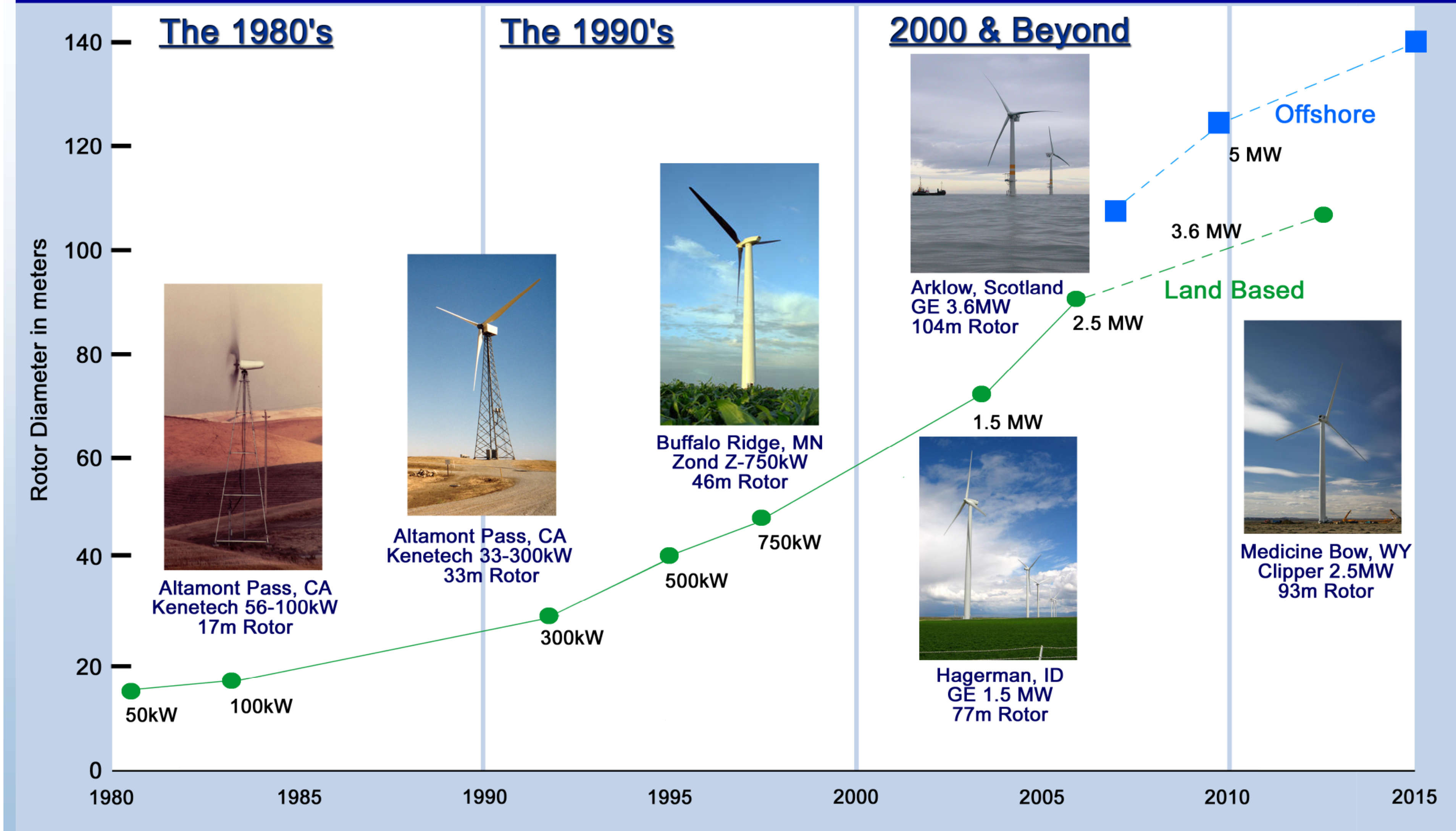
- –Typically wind farm application of 10 – 400 MW
- –Professional maintenance crews
- –16+ mph (7+ m/s) average wind speed or greater (Class 4+)



1st GE 3.2 MW – land Offshore rated at 3.6MW

BARD Engineering GmbH Germany's first 5-megawatt (MW) near-shore in 2- to 8-meter deep water at Hooksiel off North Sea coast.

Evolution of U.S. Commercial Wind Technology



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WIND POWERING AMERICA

NREL National Renewable Energy Laboratory

Questions?

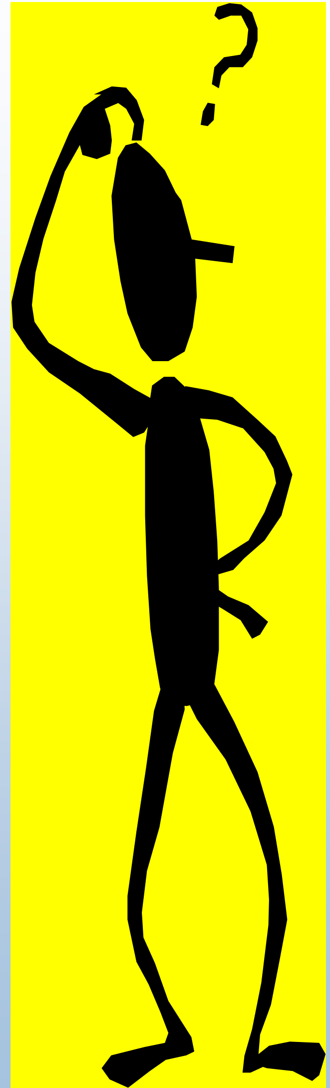
For more info:

http://www.nrel.gov/wind/

http://www.eere.energy.gov/windandhydro/windpoweringamerica/

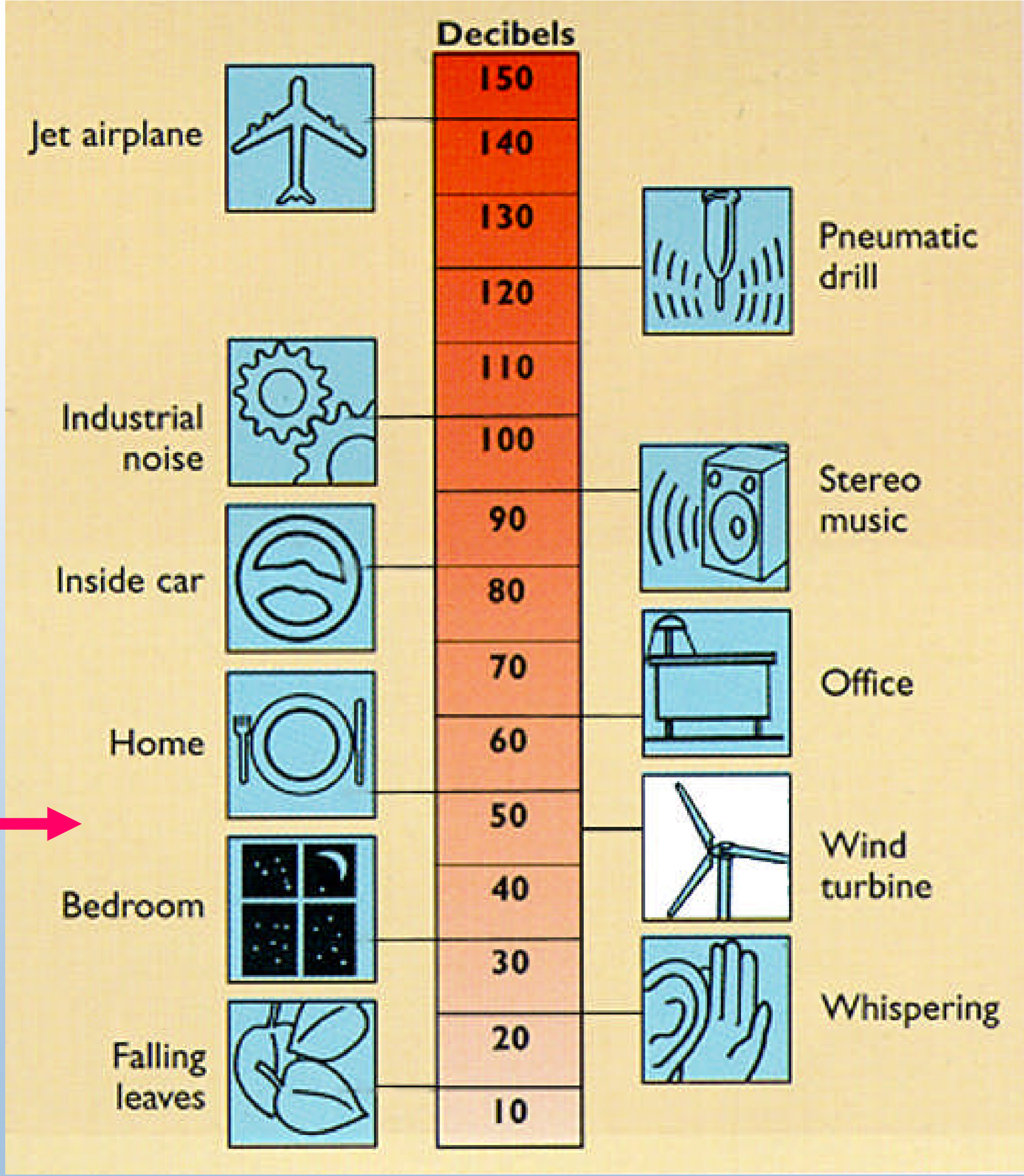
http://www.awea.org/

http://rredc.nrel.gov/wind/pubs/atlas/



Wind and Noise

Turbine at 225-300m setback



Economics of Wind Development

- What 1,000 Megawatts of Wind Brought to Texas
- Taxable value of wind power plants: $777 million
- Property tax payments to local school districts:
- $11.6 million in 2002
- Landowner royalty income: $2.5 million in 2002
- Wind-related jobs: 2,500

Need to “Back-up Wind with Firm Power

Study in Minnesota

1500MW of wind

8MW of backup power needed to augment wind